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FOREWORD

With the progressive and rapid expansion of industrialisation in various fields during the post-independence period, the need to intensify efforts for locating and developing mineral resources, specially those of copper and other base metals was being keenly felt. An attempt to assess the availability and requirements of base metals was made by the publication of a Bulletin entitled 'Base Metals in India' by the Indian Bureau of Mines in the year 1959. Another Bulletin (No. 23, Ser. A - Economic Geology) dealing with the occurrences of copper as at the end of 1962 was published in the year 1965 by the Geological Survey of India. This was a revision of the Bulletin on 'COPPER' published in the year 1952 by the G. S. I. as Bulletin No. 11 of Records, Vol. 76.

In order to assess the actual position with regard to the demand of copper, exploration and exploitation of known deposits of copper-ores and location of new or little known occurrences a Symposium was held on the 19th August, 1961 in the Geological Survey of India. The Symposium was attended by not only the officers of the G. S. I. but also delegates from several other Govt. Departments, public and private undertakings, universities, etc.

With the growing importance of copper and other base metals in the expanding industries, many other symposia were held subsequently from time to time. A symposium on Base metals in India was held in the Geological Survey of India, Calcutta, in July 1966. More recently a colloquium on 'Exploration and Development of Non-Ferrous Metals' was held in the G. S. I., Northern Region, Lucknow in October 1968 and still later a Symposium on 'Non-Ferrous Metals Technology' was held in December 1968 at the National Metallurgica Laboratory, Jamshedpur.

The position of reserves of copper, lead and zinc ores has improved considerably during the last few years as a result of intensified exploration carried out by the Geological Survey of India and other organisations. The need for copper and other base metals is far more

than the present production. All out efforts are being made to step up the production by exploring the known deposits and endeavouring to locate new ones.

Though this publication contains selected papers presented to the Symposium held in 1961, it could not be brought out earlier due to some unforeseen difficulties. It is, however, expected that the information presented will be useful to all those interested in the subject.

Calcutta
28-12-68

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21 OCT 1969

A REVIEW OF THE WORK OF THE BASE METAL UNIT AND SUGGESTIONS FOR STEPPING UP PRODUCTION OF COPPER

By

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Geological Survey Of India

ABSTRACT

The paper describes the major results of the investigations that the Geological Survey of India has carried out in recent years in the various copper bearing areas in the country in its endeavour to locate centres with high potentiality, some of which may in due course become ore producing fields. Further more, to attain the self-sufficiency in metal, it is essential to encourage the use of substitute metals, though complete replacement of copper may not be possible.

Recent researches have made it possible to utilise ores of low grades. Recovery of by-products is very important in copper industry in India. One of the by-products is sulphur of which indigenous sources are not known. Other by-products are nickel and selenium metals.

INTRODUCTION

A sharp increase in the tempo of industrialisation after independence has made the problem with regard to the procurement of supplies of all the essential metals, particularly the base metals *viz.*, copper, lead, zinc, nickel, etc. intensely acute. Amongst these copper is most vitally affected on account of its unavoidable use in many essential and domestic appliances as also in the armament. The magnitude of the problem can be assessed from the fact that the requirement of the metal has increased from about 37,000 tonnes in 1948 to 83,000 tonnes in 1960 while the indigenous production has remained static around eight to nine thousand tonnes. It is further noted that the consumption of copper alone far exceeds that of lead, zinc and nickel put together. This is causing an increasing drain on the foreign exchange on this account. In 1960 alone about 63,000 tonnes of copper valued at about Rs. 24 crores had to be imported. Further, it

is estimated that by the end of the Third Plan (1961-66), the consumption of this metal would rise to nearly 170,000 tonnes, which would mean proportionately larger drain on the foreign exchange resources, unless the production is increased substantially. It is, therefore, of prime importance to not only check the ever widening gap between the production and consumption of copper, but also to make an all out effort to attain self-sufficiency in this metal.

At present, there is only one copper producing centre in the country which is located at Ghatsila in Singhbhum district, Bihar, and is owned by the Indian Copper Corporation. The annual production at this place ranges around 9,000 tonnes. The Corporation is, however, taking steps to increase this figure substantially. A plan for the erection of an electrolytic plant with an annual capacity of 10,000 tonnes has been approved by the Government and is likely to be implemented within the Third Plan period (1961-66).

The National Mineral Development Corporation has recently taken over, for developing, the Madhan-Kundan block, where a reserve of about 29 million tonnes of ore averaging 0.8 per cent. copper has been proved by the Indian Bureau of Mines. The Daribo prospect with about 0.5 million tonnes of ore averaging 2.5 per cent. copper, would supplement the reserves of Madhan-Kundan area. It is expected that a plant with an annual capacity of 10,000 tonnes of copper, to be increased to 20,000 tonnes in due course from the ore raised from these two prospects in Rajasthan would be erected near Jaipur by the end of the Third Plan period. Thus it may be expected that an annual production of nearly 30,000 tonnes of copper from indigenous ore and another 10,000 tonnes from imported matte may be reached by the end of the current plan. This would leave a gap of nearly 140,000 tonnes between the consumption and production.

SCOPE OF WORK

Although the Geological Survey of India had examined all known copper occurrences in some measure, a detailed systematic geological mapping of the two most promising areas, the Singhbhum copper belt in Bihar and the Khetri copper belt in Rajasthan was commenced in 1954. Geophysical exploration was also carried out alongside in the Gani and Kalava fields in Andhra Pradesh as also in

parts of the Khetri field. In January 1959, the Base Metal Unit was set up within the Survey with a view to co-ordinate and intensify the investigations all over the country for copper, lead, zinc and nickel. The unit drew up a schedule of work for assessing the potentialities of the various occurences on the basis of available information. To begin with, there were only eleven technical officers in this Unit, but its strength was steadily increased to 62 officers in 1960-61 with four Superintending Geologists of the Economic Geology circles supervising the parties in their respective circles.

Detailed investigations including geological mapping on various sclaes, geochemical and geophysical prospecting, trenching and pitting and in a few cases drilling also were carried out by this Unit in several mineralised zones. These included the promising areas in Agnigundla, Gani Kalava and Garimanipenta areas in Andhra Pradesh ; Singhbhum copper belt in Bihar ; Doda, Sindh Valley and Ramsu-Riasi areas in Jammu and Kashmir ; Munda Tikra area in Madhya Pradesh ; Mamandur area in Arcot district, Madras ; Malyadi area in Mysore ; Subansiri area in NEFA ; Narnaul and Simla areas in Punjab ; Alwar-Jaipur-Sikar areas in Rajasthan ; and Almora, Chamoli and Pithoragarh areas in Uttar Pradesh. An overall area measuring about 2,800 sq. km. has been mapped on small sclaes including 1,63,360, 1,31,680 and 1:15,840 and about 24 sq. km. on large scales (1,2,400 to 1,1,200). The aggregate length of the bore-holes drilled is about 2,800 m. The State Governments of Madras and Mysore and the Indian Bureau of Mines have greately assisted the Base Metal Unit by providing some drilling equipment.

RESULTS OBTAINED BY THE UNIT

The foremost amongst these, is the recent discovery of a seven metre-wide ore zones averaging over two per cent, copper in the Roam-Sidheswar block, situated about 25 km. north-west of the existing copper mines at Mosaboni in the Singhbhum district, Bihar. The mineralised zone has so far been found to extend for about 1,200 m. on the basis of the present indications, about 15 million tonnes of ore may be expected in the block upto a depth of about 600 m. Besides that, inferior ores, containing 1.5 and 0.8 per cent. copper are also expected to add considerably to the reserves. In addition, quite encouraging indications of mineralisation have been observed in several other blooks

of the Singhbhum belt *viz.*, Rajdah, Ramchandra Pahar, Tama Dungri, and Tama Pahar.

In the Khetri copper belt which was so far known to extend from Singhana to Babai, a distance about 35 km., indications of mineralisation have been found intermittently further south-westward beyond Babai, for nearly 55 km. A few prospects located in this extension of the belt *viz.*, Satkui and Dhanaota, appear to be fairly promising. In the north, copper lodes in the Madhan-Khudan block where a reserve of nearly 29 million tonnes has recently been proved, are found to continue for another two kilometres in a north-eastward direction. Encouraging evidences of copper mineralisation have been observed in the several old mining areas., *viz.*, Pratapgarh, Nalladeshwar, Bairat, Jodhawas and Matasula, etc. in Alwar-Jaipur districts.

In situ lodes of the reported occurrences of copper-ore in the Sindh valley and Doda areas in Jammu and Kasmir have been located, a prominent zone of mineralisation being noticed at the former place.

A 27 m. wide copper mineralised zone has been located in one of the drill holes in the Kalyadi area, Mysore State. Investigations to delineate the extent and the nature of the ore body are being pursued with encouraging results.

Indications of multisulphide mineralisation met with recently in the course of surface investigation in Manandur area, Madras, have been confirmed by a few drill holes.

A copper mineralised zone extending for over two kilometres in length has been brought to light in the course of detailed surface work carried out recently in the Agnigundla area, Andhra Pradesh. The Gani-Kalava prospect in Andhra Pradesh was tested by shallow drilling in collaboration with the Indian Bureau of Mines, but only a few small mineralised zones were found in the area. However, before giving up the area as completely uneconomic, it would be desirable to do some deep drilling.

In the course of traverse mapping the parts of Bastar district, Madhya Pradesh, several gossan zones were noticed. Detailed work

including drilling is being pursued in one of them, and several leached and sulphide zones have been intersected so far.

The mineralised belt of Almora-Chamoli-Pithoragarh districts in Uttar Pradesh, has been mapped in detail. Although there exist a number of abandoned old workings in the belt, the indications of mineralisation on the surface and in a few old workings opened for inspection have been found to be rather scanty. However, geophysical prospecting and drilling is contemplated before abandoning the area as it is quite likely that the ancients might have removed only that part of the ore which was easily ascessible.

In brief, it may be mentioned that the recent investigations indicate that some of the prospects including Roam-Sidheswar, Ramchandra Pahar, Tama Dungri in the Singhbhum belt, Satkui and Dhanaota in the Khetri belt, Pratapgarh area in Alwar district, Sindh valley, and Kalyadi Agnigundla, in the south hold fairly good promise and may in the near future help to increase the indigenous production very substantially. Beside these, the Rakha mines in the Singhbhum belt and the Baragunda mines in Hazaribagh district ,Bihar, which had been worked by modern mining methods and later abandoned due to factors other than the absence of ore, if developed, may yield a good quantities of ore. The Rakha mines are, in fact, reported to have been developed up to 9th level (245 metres depth) by the Cape Copper Company. The stoping in these mines was done mostly up to the 6th level by 1922 when the operations were suspended. Similarly in the Baragunda mine where the ore is reported to assay on the average 1.0—1.5 per cent. copper, five levels were developed by the Baragunda Copper Company between 1882 and 1892 when, possibly due to lack of funds, the mine was closed.

USE OF SUBSTITUTES

In addition to the development of the various prospects and mines mentioned above, it would be desirable to conserve the metal for essential purposes only and encourage the use of substitute metals. Though complete replacement of copper by alternative metals may not be possible, a substantial saving in the use of copper can be effected by progressively restricting the use of the metal for only absolutely essential purposes. The consumer industries and the National laboratories may be encouraged to undertake intensive research about the feasibility

of alternative, as also cheaper substitutes for copper for different uses. Aluminium is already coming up in the picture and further researches should help in finding incresingly more ways of replacing copper by alternatives.

UTILISATION OF LOW GRADE ORES

Recent advances in technology have made it possible to utilise ores of low grades, bearing sometimes as little as 0·5 to 0·7 per cent. copper. It is apparent that when the metallic contents are low, the total amount of ore that will have to be mined and processed will have to be proportionately large. Hence it is essential that an ore body of low grade has to be of a very large size before it can be worked economically.

It may be noted that in the interest of national economy it would be essential to keep the limit of cut-off grade in any mineable prospect as low as possible, so that the least amount of cupriferous rock is allowed to be wasted. If a certain property bears sizeable quantity of ore with two per cent and above of copper, there might be a tendency to keep the cut-off limit at two per cent. Such a policy might bring large dividends in the early stages but will obviously reduce the life of the property, and even more than that, cause a serious depletion of the ultimate resources of the country. Once the richer lodes and pockets have been used up, it would become almost impossible to utilise the lower grade ores.

The available proved quantity of ore with over two per cent. copper is extremely limited in India. If self-sufficiency is to be aimed at, there is no doubt that ores of lower grades must be utilised by appropriate blending and processing. In Khetri, for instance, there are very large quantities of ore, bearing 0.8 per cent. copper. Similarly in Mosabani also the available quantity of ore with only one per cent. copper is likely to be of a very high order. It is most essential that ways and means of treating these low grade ores must be found so that the cut-off limit is kept as low as possible. It may be noted that under the present practice the cut-off grade at Mosabani is 1·8 per cent. It is, therefore, necessary that the problem be examined in detail, to see how best the cut-off grade can be lowered without impairing the efficiency of the existing smelting plant.

BY-PRODUCTS

Full recovery of by-products is very important in the economics of any industry, and it is even more so in the case of copper industry in India, as the likely by-products are of great strategic value and at the same time are also in short supply. In India there are no indigenous sources of any sizeable order of native sulphur, and the country depends very largely on imports from abroad. Most of the copper-ores are sulphides and bear chemically combined sulphur in large quantities. The amount of sulphur that is present in the chalcopyrite ore is almost equal by weight to that of copper. In other words for every tonne of copper produced, a tonne of sulphur is also liberated. Under the prevalent practice at Maubhandar this sulphur is allowed to escape in the atmosphere. It should, however, not be difficult to devise a contrivance to recover it in a substantial measure. By endeavouring to recover this escaping sulphur, two-fold objectives would be simultaneously served, firstly strengthening of the economy of the copper industry, and secondly securing supplies of a strategic substance.

Another important by-product that is possible in the copper industry in Singhbhum is the very valuable metal, nickel. This is yet another substance for which there is practically no known source in the country, and, therefore, its recovery would once again be of additional advantage. It has been reckonoed that the Maubhandar smelter averages to about 3.4 per cent. In other words for every 1000 tonnes of copper 34 tonnes of nickel are also being preduced, which under the present metallurgical practice is not recovered. If arrangement could be made for refining the copper electrolytically, the bulk of the nickel could be easily separated out and recovered.

In addition to nickel, the copper-ore from Mosabani contains small traces of the rare metal, selenium, which can also be recovered through refining by electrolysis. The average amount of selenium present is about 5 tonnes for every 10,000 tonnes of copper. To sum up, for every 10,000 tonnes of copper, by-products worth Rs. 45 lakhs can be recovered in the copper industry in Mosaboni area as per details given below :—

15,000 tonnes of sulphuric acid ...	Rs.	15,00,000
300 tonnes of nickel ...	Rs.	27,00,000
4 tonnes of selenium ...	Rs.	3,00,000
Total	Rs.	45,00,000

This means that in producing copper valued at about Rs. 3,00,00,000 (at Rs. 3000 per ton), it is possible to recover by-products worth Rs. 45,00,000. In effect it would mean an economy of about 15 per cent. Making a further allowance for lesser recoveries and for the cost of setting up and operating the additional plant for recovering the bye-products, the figure may further be reduced to 10 per cent. which also would be quite sizeable. In addition the country would also get substantial quantities of sulphur, nickel and selenium, all of which are very much needed by the country. This aspect of the copper industry is very vital and deserves special attention.

SELF-SUFFICIENCY IN COPPER

BY

H. R. DEWAN, V. K. S. VARADAN, K. S. MAHAPATRA, M. NARASIMHAN, AND N. K. MUKHERJEE

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ABSTRACT

The annual consumption of copper by the end of the Fifth Five Year Plan 1971-76 is estimated at around 304,000 tonnes.

The scope of aluminium as a substitute for copper has been examined and the conclusion reached is that the general policy should be directed towards maximum production of both the metals and not based on aluminium being able to substitute copper to a large extent.

The question of mining low grade ores of copper has been discussed. Under suitable conditions, low grade ores running around 0·5 per cent. copper, have been mined economically by opencast methods.

Exploration for copper should take into account the immediate need for self-sufficiency as well as the long range requirements.

INTRODUCTION

It is well known that the present production of copper in India is very inadequate in comparison with the requirements. These requirements too, will greatly increase in future as a result of rapid industrialisation of the country. The gap between production and consumption, which is wide at present will become even wider in course of time unless the production is stepped up to the maxium extent in as short a time as possible.

The paper attempts to answer the following critical questions. (1) If the country can achieve self-sufficiency in copper (2) If so, how soon? (3) The factors to be taken into account while framing policies and drawing up programmes for achieving self-sufficiency (4) In what directions action is called for to attain self-sufficiency as well as the long range objective of developing copper resources of the country to the maximum extent possible (5) The long term measures to be employed for achieving the above.

SELF-SUFFICIENCY IN COPPER

The question of self-sufficiency naturally involves a consideration of the immediate requirements as well as anticipated requirements in the foreseeable future. The country's consumption of copper metal in 1960 was 86,000 tonnes. During the same year, the internal production was 8,910 tonnes.

The anticipated consumption of copper by the end of the Third Five Year Plan is 172,000 tonnes. No authentic estimates are available for the anticipated consumption by the end of the Fourth Five Year Plan. The great increase of consumption during the Second Five Year Plan (1956—40,600 tonnes, and 1961—86,000 tonnes) and the further increase anticipated during the Third Five Year Plan clearly suggest that the requirements for subsequent years will show a steep upward trend. It is, therefore, evident that the concept of self-sufficiency, which is related to requirements, is one that calls for the establishment of an equilibrium between production and consumption, or in other words, self-sufficiency should not be thought of as a fixed figure of production. What, in fact, is likely to happen is a steep rise in consumption up to a certain point and then a comparatively steady but gentler up ward trend.

Since for the present purpose, consumption is required to be known for later periods, an approximate estimate may be attempted on the basis of the per capita consumption of copper at which the steep rise in consumption may reasonably come to an end. Since, during this period, the rise in consumption is much greater than the rise in population, for the purpose of approximate estimates the population may be considered stationary at the figure of 400 millions. On this basis, the per capita consumption of copper in India at the beginning of the Second Five Year Plan was 0.2 lbs. In 1960 this figure has risen to 0.4 lbs. The estimated consumption by the end of the Third Five Year Plan represents a per capita consumption of the order of 0.8 lbs. A reasonable anticipation would be that the consumption trend would assume a gentler rate of rise around per capita consumption of 1.5 lbs. of copper and that this would be reached by the end of the Fifth Five Year Plan. This implies a four-fold increase in the per capita consumption over the present rate. Corresponding to a per capita consumption of 1.5 lbs., the annual consumption works out at 304,000 tonnes.

If an annual rate of production of copper metal of the order of 304,000 tonnes can be achieved by the end of the Fifth Five Year Plan, the country can be expected to attain the stage of self-sufficiency in copper during the Sixth Five Year Plan. That the figure of 304,000 tonnes is not over-ambitious, will be evident from the fact that the per capita consumption in the United States and Europe is 17 lbs. and 5 lbs. respectively.

An annual production rate of 304,000 tonnes of copper is not likely to prove inadequate from the point of view of ensuring self-sufficiency. From the Sixth Five Year Plan onwards, significant quantities of scrap copper will become available for consumption. It has been estimated that primary copper comes back into circulation as scrap after a period of around 25 years. The quantity recoverable is about 60 per cent. The contribution from scrap during the Sixth Five Year Plan may be of the order of 25,400 tonnes. In the course of the next 20 years a figure of 182,000 to 203,000 tonnes may be reached. The important conclusion drawn from this is that, even if the primary production of copper is maintained at 304,000 tonnes, it would be ultimately possible to sustain progressively increasing rates of consumption. This increase in the total consumption will be possible at a higher rate than the likely rate of increase in the population, so that slowly but steadily the per capita consumption of copper will be increased, despite the fact that the primary production is stationary. Moreover, the actual metal in use at any time will greatly increase.

The scope of Aluminium as a substitute in relation to the problem of ncy in Copper.—Another important consideration is the extent to which copper can be substituted by other metals. Aluminium is by far the most important substitute metal for copper. The known resources of bauxite in India are greater than those of copper-ore The total resources of bauxite have been estimated at about 250 million tonnes. Out of this, 30 million tonnes are estimated to be of metallurgical grade. On the basis of one tonne of aluminium metal for five tonnes of bauxite, 30 million tonnes of bauxite represent a potential source capable of yielding six million tonnes of aluminium. Assuming the existence of a minium of 30 years reserve the known resources can be regarded as capable of producing 203,000 tonnes of metal annually. The consumption of aluminium in 1961 was 50,800 tonnes. The estimated consumption by the end of the Third Five Year Plan is, 101,000 tonnes. If it is assumed that an aluminium metal consumption

of 1.5 lb. per capita to be the point at which the steep rise in consumption will cease, the total consumption corresponding to it works out as 304,000 tonnes. This implies that reserves of the order of 45 million tonnes (equivalent to a life of 30 years) will have to be proved before production on a scale of 304,000 tonnes of aluminium metal can be undertaken. It is thus evident that if aluminium is to make a substantial contribution to the solution of the problem of self-sufficiency in copper as a substitute metal, the resources of bauxite have to be considerably improved. There is, therefore, an urgent need for greatly increasing the tempo of exploratory and proving operations for bauxite in the country.

Power requirements may prove to be a bottleneck in stepping up production of aluminium beyond a certain limit. Power consumption for production of a pound of copper is around 1.2 to 1.7 kw., while that of aluminium is 10 to 11 kw. In terms of cost, therefore, power requirement per pound of aluminium is 15 to 20 times that of a pound of copper.

Since hydro-electric power can be made available at a cost which will permit the production of aluminium economically, the capacity for aluminium production has to take into account the country's hydro-electric potential. The present total installed capacity of hydro-electric power stations in India is around two million kw. The estimated capacity by the end of the Third Five Year Plan is 4·75 million kw. The estimated total potential of the country in hydro-electric power is 41 million kw. Even on the basis of the installed capacity in hydro-electric power being doubled during the Fourth and Fifth Five Year Plans, the installed capacity at the end of the Fifth Plan works out to about 19 million kw. which is 46 per cent. of the estimated total potential of the country. A higher rate of increase cannot reasonably be anticipated. In view of the heavy demand for power in industry, it would be reasonable to expect that the same proportion of power will be made available to the aluminium industry, as at present provided for under the Third Five Year Plan. This implies that from the point of view of availability of power, we can reasonably anticipate a maximum production of aluminium metal to the tune of 304,000 tonnes by the end of the Fifth Five Year Plan. Thus the scope for substitution of copper by aluminium appears to be a marginal one.

Another important point to be considered is that for many purposes copper can be effectively and economically substituted by aluminium ; actual trends in this direction show that copper continues to figure as a major metal in industry. What is actually taking place is that a far greater share in the increased metal consumption is accounted for by aluminium. As far as India is concerned, the present level of consumption for both the metals is so low that there is bound to be an increase in the consumption of both the metals in the future.

The conclusion of practical import which emerges from the above discussion is that the general policy should be directed towards maximum production in both copper and aluminium and not based on aluminium alone in the context of its substitution for copper to a large extent.

SELF-SUFFICIENCY IN COPPER BY 1976

Prospects And Programmes

Provided copper production can be stepped up to 304,000 tonnes by the end of the Fifth Five Year Plan (1971-76) the country can be expected to be self-sufficient in copper during the Sixth Five Year Plan.

The present output of copper (1961) is of the order of 8,600 tonnes. To achieve the target stated above, production has to be increased by 35 times within a duration of 15 years. The geological mode of occurrence of the ore bodies, the degree of accuracy to which the size, shape, attitude and grade of the ore body has to be ascertained, the time, cost and complexity involved in proving and appraisal of ore reserves etc., combine to militate against ascertaining the reserves in advance of exploitation. The known life of the reserves is usually in the vicinity of ten years and seldom exceeds 20 years. It is only after detailed proving operations are conducted, any definite statement can be made with respect to the production.

To the question of whether adequate reserves can be proved to sustain production of the order of 304,000 tonnes by 1976, the answer is in the affirmative, provided we succeed in finding at least two or three large low-garde deposits, during Fourth and Fifth Five Year Plans. In the light of experience gained by the Indian Bureau of

Mines, as a result of detailed proving operations and reconnaissance survey of a number of copper prospects in the Khetri and Dariba copper districts, the chances of finding large low-grade deposits appear to be promising.

The estimated production by the end of the Third Five Year Plan is 27,400 tonnes which will be accounted for from the following sources :—

(1) Maubhandar	...	8,600 tonnes of fire refined copper.
(2) Maubhandar	...	8,600 tonnes of electrolytic copper.
(3) Khetri	...	10,200 tonnes of electrolytic copper.
Total		27,400 tonnes.

At the beginning of the Fourth Five Year Plan, there would be operating mines in the Madhan-Khudan section of the Khetri belt, in the Dariba deposit and in the Mosabani and Surda copper deposits of the Singhbhum copper belt. On the basis of additional ore likely to be proved in these mines in the course of the Fourth Five Year Plan, additional production targets of 13,000 tonnes from Rajasthan area, and 10,000 tonnes from Singhbhum area from the operating mines can be programmed. This works out to a total of 50,000 tonnes by the end of the Fourth Five Year Plan from mines in operation during the Third Five Year Plan.

This production is likely to be accounted for in the following manner :—

(a) From prospects converted into mines in Rajasthan.	30,500 tonnes.
(b) From prospects converted into mines in Singhbhum copper belt.	15,300 tonnes.
(c) From prospects converted into mines in other areas.	5,000 tonnes.

Proving operations will also be conducted in prospects in Jammu and Kashmir, Kulu Valley, Andhra Pradesh and other areas where promising prospects come to light. In the above anticipations

any success that may be achieved in prospects in these areas has not been taken into account. They will provide a safety margin to make good any shortfalls in production from the other prospects. It will thus be seen that the present anticipations are that a production target of 100,000 tonnes of copper metal can be achieved by the end of the Fourth Five Year Plan.

To achieve a target of 304,000 tonnes by the end of the Fifth Five Year Plan, an enormous leap forward in production has to be taken during the Fifth Five Year Plan. Moreover, the scale of exploratory and proving operations during the Fourth Five Year Plan will have to be enormously increased.

The large reserves required for sustaining the increase in production of 200,000 tonnes of metal can be proved, only if at least a few large low-grade deposits are found,

MINING OF LOW-GRADE COPPER ORES

In mining terminology the term ore implies any mass of rock containing minerals which can be extracted and marketed economically. The grade of economic ore, therefore, depends on the cost of extraction, and marketing and the sale value of the recoverable portion of the valuable constituent of the ore. As the costs of extraction and unit sale value vary from time to time and according to the nature of the deposit, what constitutes an ore at any time is unrelated to the physical existence of mineralised rock masses in the ground. A scrutiny of average grade of copper ores mined over a period of years indicates a progressively declining grade of ore so that what now is mined as an ore was once considered as economically unworkable. The great emphasis on what constitutes economically workable ore, is responsible to a large extent for the present lack of adequate knowledge of the mineral resources of the world and for the wastage of substantial tonnages of material which were not ores at the time they were mined, but which can now be economically worked. Only during 1960, an American mining engineer would not dare to recommend the mining of ores containing less than two per cent copper, yet in 1930, the copper mine at Maimi was producing ores averaging 13.7 lbs. of copper per ton and yielding about 10.55 lbs. of refined copper per ton of ore, at an operating cost of 9.933 cents

per pound of metal. Around 1929, the Utah Copper Company mined in a single year about 17,000,000 tonnes of ore which is about 50 per cent. more than the entire reserves on which the enterprise was originally launched. That very year refined copper was produced from ores averaging 20 lbs. of copper per ton of ore, at 7 cents per pound. Yet from 1900 to 1930, the wages had increased by 50 per cent. cost of mine supplies and equipment by 70 per cent, and taxes local and federal, several hundred per cent. These spectacular achievements have, no doubt, been brought about by large scale mining of deposits of immense reserves amenable to reliable assessment of tonnage and grade by comparatively quicker and cheaper methods of exploration such as drilling, advances in the design capacity and adaptability of the modern mining machinery, improvements in the milling practices which have resulted in better and cheaper concentration of ores and higher recovery and lastly in the improvements in the smelting and refining techniques including valuable by-product recovery. The cumulative result of all these is a steady reduction of the grade of minable ore so that low grade ore should mean the leanest run-of-mine product which can be mined in the context of the technological advances and knowledge achieved at any period.

Since the workable grade is progressively going down, it is essential in any exploration programme to assess all grades of ore known to exist physically in the ground within the confines of the ore-body being explored rather than to limit assessment to grades of ore economically workable at the time the exploration is being conducted. This will enable the resources of the country to be known in advance, separate stacking of leaner grades for eventual recovery and also in judicious selection of dumping sites required for the vast quantities of wastes and tailings. For this reason, two different terms have been coined, 'ore' implying economically workable grade at the times of assessment and 'protore' implying all sub-marginal grades of cupriferous rocks which may become ores in future. This is very important especially in relation to a country's copper resources.

The grade of the copper-ore (Table 1) mined in the U. S. A. has progressively declined and the average grade of the entire mine production in 1957 was 0.77 per cent.

TABLE 1

Year	Average grade of mine production (Copper percentage)
1948-52 (Average)	0.85
1953	0·85
1954	0·83
1955	0.83
1956	0·78
1957	0·77

The progressively increasing rates of production from the various important places are also indicated in the following table :

TABLE 2

ITEMS	UTAH MINE		MAIMI MINE		
			High grade ore	Low grade ore	
	1899	1929	1923	1929	Nov. 1930
Ore developed, (millions of tons)	12·385	775.000	22,000	108.461	—
Grade ; (% Copper)	2·0	1·2	2.2	0.88	—
Cost of stripping (dollars/c. yd.)	0·75	0.30	—	—	—
Production ; (tons/day)	2,000	50,000	6,000	14,000	16,792
Recovery by concentration of copper	0·75	0.83	—	—	—
Cost of concentration, (dollars per ton of ore)	0·45	0.30	—	—	—
Average content of copper (in lbs./ton)	—	—	39.3	16.6	13.7
Net recovery of copper (in lbs./ton)	—	—	27.1	11.70	10.55
Smelter recovery %	—	—	79.78	70.61	77.1
Mining cost per ton of ore (dollars)	—	0·27	1.231	0.423	0.357
Total mining and milling per ton of ore.	—	0.57	2.141	0.934	0.713

Compartively recent data of reserves and grades of a few important mines are given in Table 3 below :

TABLE 3

ITEMS	Torquepola	Bagdad Crop.	Berkely pit.	Copper Cities Miami	New cornelia	Morenci
Production						
Ore-tons/day	30,000	2,500	18,800	12,000	31,000	52,000
Waste-tons/day	120,000	0.7% (Block caving 14 lbs. per ton)	58,100	8,000	44,470	118,000
Leach ore-tons / day	—	—	4,600	—	—	—
Total Reserves						
Ore, millions of tons.	400	30	100	3.38	40	200
Grade, % Cu.	1.0	0.754	0.8	0.7	0.04 (?)	1.036
Leach ore, millions of tons.	—	300 (0.435% Cu.)	—	—	—	—
Waste, millions of tons.	125	—	—	34.8	—	420
Shape and size of ore body.	—	1400′ x 800′ x 125′	4600′ x 2600′ x 200′	1800′ x 1800′ x 100-220′	—	—
Overburden thickness.	—	—	100 to 300′	L.O. 20-115′ (0.1%)	—	—

A study only of the average grades of copper-ores mined in any country does not enable any inference regarding the lowest possible economically workable grade of ore to be drawn. It is more important to study the production from a number of individual mines, their average and cut-off grades, scales of production, local conditions etc.

As already stated, a low-grade ore ody may be capable of being mined economically during any given period. Obviously, this

implies that the ore body will consist of substantial reserves of an ore as well as protore, so that increasing tonnages of protore may become ore with advances in technological knowledge. This olso implies that what constitutes protore at any given time should exist physically in such a condition in the ground that it is amenable to mining subsequently or if it has to be mined at any time along with ore, it should be stacked separately for eventual treatment. It also implies that the ore body should be such that what constitutes ore at any given period should be determined from time to time from assay—contacts and not from well defined clear cut geological contacts. In general, lode and vein deposits constituting rich lodes of ore with clear-cut contacts with wall rocks, oocuring singly or in groups with considerable barren masses in between will not come under the category of low-grade ore deposit. On the other hand, if rich lodes occur within a mass of comparatively leaner grade protore, then the whole of the mineralised ground would constitute a low-grade ore body. Selective mining of such a deposit should be resorted to after careful consideration both of the present and future conditions. If the richer shoots are extracted, the overall grade of the remaining mineralised ground will be appreciably lower. If in a future date, it is considered possible to work the remaining portion, the old workings will have to be filled up. In the case of the Kelley mine preparation for blocking of caving involved filling of about 9,000,000 tons of filling before commencing opencast mining. It will be seen later on that low-grade ore bodies to be profitably mined should be of suitable sizes and shapes to sustain daily production targets of 15,000 to 20,000 tons and above. Opencast and underground layouts for such large tonnages will require considerable capital investments and this can be justified only if the reserves are large. Proving of such reserves of ore by the conventional methods adopted for lode deposits *i. e*, by surface and underground drilling and underground development will be expensive and prolonged. It is essential that the shape, size and mineral distribution within a low-grade ore body should be such that it is amenable to reliable assessment of both grade and reserves by quick and cheap exploratory method, namely, drilling. It may be more profitable to mine the entire deposits in preference to selective mining whereby individual veins will be mined separately. To sum up the following are the characteristics of a low-grade ore body :—

1. The reserves of protore should be high. The distribution of the mineralisation in it shall be more or less uniform and its shape,

size and extent such that reserves and grade can be reliably assessed by drilling with subordinate amount of exploratory mining, if any.

2. The contacts of an ore at any given time within the protore is to be determined by assay contacts.

3. The rest of the protore should exist in ground in such a way that it is amenable to mining separately at a future date.

4. It is more profitable to mine the entire deposit than selective mining of the veins within it.

5. For profitable mining, production rates should be high. The overall reserves, the shape and size of the deposit should be such as to make the required tonnage of production practicable.

In India, there is only one copper mine which produces ores averaging 2.25 per cent. copper from thin lodes or veins of copper. The cut-off adopted in their assessment of reserves is also high. There are, therefore, no working deposits which will strictly fall under the category of low-grade ores. The Rhodesian copper belt also does not have low-grade ores as their production is attained from remarkably persistent beds of ore with well defined contacts with the wall rocks. The world's best examples of low-grade ores are the porphyry deposits of the North and South America and some of the cupriferous stockworks of Spain.

There has been a steady increase in the production of ore from opencast copper mines in U. S. A. In 1957, 77 per cent. of the total copper-ore production in U. S. A. was from opencast mines and the rest from underground mines. The share of the two groups, opencast and underground mines, in regard to copper, were 72 per cent. and 28 per cent. respectively. The average grade of whole of U. S. A. copper-ore produced in 1957 was 0·77 per cent. of copper so that the average grade of opencast and underground ores were 0.720 per cent. Cu and 0·938 per cent. Cu respectively. This means that the underground ores are richer than the opencast ores by about 0.2 per cent. copper, the cost being equivalent to about Rs. 7 per ton of ore.

Mining

Important advances in opencast mining which have resulted in the reduction of unit mining costs are in general (a) Improvement in the blast hole drilling techniques (b) Introduction of amonium nitrate fuel oil (AN-FO) explosives which cost a fourth of the equivalent nitroglycerine type of explosives. (c) Development of earth-movig equipment of large capacities. (d) Introduction of shovels and dumpers of large capacity and (e) Introduction of hoisting of ore by belt conveyors and skips.

Bucket wheel excavators are finding increasing applications in the digging of easily removable types of overburden. These gave the highest output per unit capital cost and their maintenance is compar-tively lower. The copper mining industry, in general, uses power shovels of 2.9—5.8 cu.m (5-10 c. yd.).

To appreciate the extent of cost reduction in the different items of expenditure the following break up of costs for 3 c. yd. and 6 c. yd. shovels are given below :

TABLE 4

Items	3 c. yd.	6 c. yd.
Tons of Waste handled	226,278	1,536,578
Labour dollars/ton	0.0142	0.0048
Payroll taxes	0.0010	0.0002
Vacation and bonus	—	0.0001
Lubrication	0.0020	0.0006
Miscellaneous	0.0046	0.0017
Maintenance and repairs	0.0354	0.0083
Industrial Insurance	0.0012	0.0003
Power	0.0046	0.0015
Total	0.06	0.02
Tons handled per shift	3328	8204

It will be seen that a 6 c. yd. shovel gives almost 2.5 times the output of a 3 c. yd. shovel per shift and the unit cost of operation is much less than a 3 c. yd. one in every item. The costs on account of labour, pay roll taxes, lubrication, miscellaneous, maintenance and repairs, industrial insurance and power are 2.95, 5, 3.3, 2.7, 4.2, 4 and 3 times the corresponding figures for a 6 c. yd. shovel.

The comparative unit cost of transport by trucks of different capacities is given in Table 5 below :

TABLE 5

	20 tons	22 tons without torque converter	22 tons without convertor	30 tons	50 tons	Diesel 40 tons	Butan 40 tons	Turn	Rockers
Tons hauled	147,228	3,100,105	535,933	5,346,676	756,670	3,538,162	59,172	25,414	60,537
Cost per mile	1.68	1.09	1.71	0.94	1.92	1.20	0.96	2.66	1.42
Cost per ton	0.088	0.063	0.087	0.046	0.051	0.038	0.036	0.106	0.045
Operating cost									—
Repairs	0.1340	—	—	0.0238	—	0.0368	—	—	—
Parts	0.3931	—	—	0.1247	—	0.1543	—	—	—
Tyres & Tubes	0.3383	—	—	0.2161	—	0.2180	—	—	—
Oil and grease	0.0370	—	—	0.0219	—	0.0318	—	—	—
Fuel	0.2465	—	—	0.2030	—	0.2679	—	—	—
Operating costs	0.5352	—	—	0.3465	—	0.4897	—	—	—
Total	1.68	—	—	0.94	—	1.20	—	—	—

It will be seen from the above table that the unit cost does not steadily decrease with increase in the capacity under comparable conditions. The total cost as well as the various sub-items of costs excluding repairs are the lowest for a 30 ton-truck. It is further observed that one of the largest single items of expenditure for the large-size models is the fuel cost. As fuel cost for diesel operation is higher, there has been recently a tendency to introduce large units of equipment which are electrically operated.

Apart from the obvious advantages of continuity of production and a stationary location for quite a long period, unit cost of transport by conveyors is cheaper. The following comparision of costs are relevant :—

TABLE—6

Comparision of truck and conveyor haulage cost

	30-ton truck	40-ton truck	Conveyor
Material hauled (tons)	1,548,290	932,560	1,351,513
Material hauled Per hour (tons)	127·5	151.05	254
Cost per ton (Dollars)			
Labour	0.0196	0.0178	0·0139
Payroll tax	0·0098	0·0008	0·0005
Tyres and tubes	0·0179	0·0106	0·0002 (supplies)
Lubrication	0·0048	0·0035	0·0123
Fuel etc.	0.0138	0·0137	0·0018
Total Cost	0.0873	0·0773	0·0396

Recently, a relatively inexpensive formula for the surfacing of haulage roads was reported from open pit operations in Navada. Successful and durable surfacing of roads has been possible by using ammonium legnin sulphonate. Three miles of main haulage roadway 40 ft. wide and sealed 36 ft. have been surfaced at an inclusive cost of £ 1,400 per mile (Rs. 18,200 per mile.). So successful is this treatment of road surfaces that it was introduced in the Yerington property and is proposed to be introduced in the Berkeley pit of Anaconda. Another trend, calculated to reduce transport costs, is the introduction of large capacity skips. Skips with capacities of the order of 10-12 tons are fairly common. They have also invaded opencast mining where the vertical lift is high.

The use of low-cost ammonium nitrate-fuel oil blasting is fairly common. It costs 25 per cent. of the cost of nitroglycerene explosives.

The smallest size of the hole for successful use of ammonium nitrate explosives is around three inches diameter. In the Anaconda's Berkeley pit, about 5·35 tons of material were blasted by 1 lb.of ammonium nitrate-fuel oil explosive. The prices of fertiliser grade ammonium nitrate and dynamite are 3½ cents and 18-20 cents per lb. respectively.

In underground mining, block caving, open room and piller methods and sub-level stoping by longhole drilling have resulted in a reduction in the unit mining cost and hence the average tenor of economically minable ore. Similarly, improvements in underground loading, hauling and winding machinery have enabled progressively low grades of ore to be mined. One very important point in the mining of low-grade ore deposits is that the mines should generally be laid out for large production.

With improvements in mining methods and machinery, there have been improvements in the milling efficiency and machinery. Development of LPF (Leach-precipitation-flotation) methods for mixed sulphide-oxide-ores, controlled roasting and leaching of lean sulphide ores, segregation process and bacterial leaching process have converted the hitherto potential wastes of lean ores to potential sources of metal. In the Anaconda Berkeley pit, all material in the pit containing 0·20 to 0·39 per cent. copper is termed 'leach ore' and is transported to a separate section of the waste dumps to be leached of its copper content. In the copper mines, the so-called mine waste analysing 0·1 per cent. copper is dumped separately and is allowed to collect in a dam across natural drainage channels. In 1956, 4,233,462 lbs. of copper was recovered by leaching these dumps. In the Bagdad mine, all leach ore is separately stacked to be ultimately leached by applying a roasting, leaching and electro-winning process, which is being developed.

Recently, the capacity of the Ray Div.'s concentrator has been increased from 15,000 to 22,500 tons per day. It has been possible to recover two lbs. of copper metal from every ton of leach ore in the L. P. F. plant.

The cumulative effect of all these is a steady decrease of the grade of the economic minable ore or an increase in the overburden to ore ratio for a given grade or ore.

It is interesting to record that large scale mining of low-grade ore not only results in low unit cost per ton of ore, but also per lb. of metal compared with small scale mining of richer sections of the ore body. The latter is more costly by the costly methods of selective mining, excessive development cost, small production rates from stopes etc. The following comparative costs of production of ore from high grade and low grade sections of the Miami Copper mine will bear out this statement :

TABLE 7

High-grade and Low-grade Operations at Miami

Recoveries and costs	High grade	Low grade	
	1923	1929	Nov., 1930
Recoveries :			
Tons concentrated/day	6,600	14,000	16,792
Average copper content lbs./ton	33.9	16.6	13.7
Ratio of concentration	29.45	60.0	64.8
Recovery, net smelter, per cent.	79.78	70.61	77.1
Copper in concentrate per cent.	41.47	36.24	35.2
Copper, net lbs. per ton of ore.	27.1	11.70	10.55
Costs :			
Mining, per ton of ore, dollars	1.231	0.423	0.357
Concentrating of ore, dollars	0.621	0.359	0.249
General, per ton ore	0.289	0.152	0.107
Total to concentrates/ton of ore	2.141	0.934	0.713
Total to concentrates/lbs. of copper	0.079	0.797	0.0676
Explosives per ton of ore	0.327	0.272	0.136
Power, per ton of ore concentrated (kw)	12.70	12.34	11.93

It is clear that large mineralised ore bodies should be mined on a large scale in preference to selective mining of its richer sections only. This will result in less unit cost per ton of ore, increase of copper production and national resources and more profit per pound of metal produced. Another advantage is that large scale mining of low-grade ore bodies will permit large refining plants to be set up and the valuable by-products to be recovered. The sulphur in the ore body can be utilised to leach leaner grades of ore, the iron to precipitate the copper in addition to recovery of by-products such as cobalt, molybdenum, gold, silver, germanium, gallium, thallium, indium, etc.

The tendency over the past few years indicates that there has been a preference to an opencast mining as the method for exploitaton of the low-grade copper-ores. Such a tendency is a result of the higher waste to ore ratio which can be mined on account of improvements in mining and technology. The most important consideration is economy which is governed by the ultimate waste : ore ratio. This ratio will depend not only on the overburden lying vertically over the ore body but also on the shape of the ore body, the safe angle of the pit sides from stability and safety point of view and the wastes to be removed to provide access to the ore body. Shape of the ore body is very important. A circular or partly circular ore body is favourable for an opencast mining than an elliptical one of similar section. The topography should be favourable to provide adequate space for dumping wastes and lean ores. Opencast mines, however, require longer period for development, being three to four years as compared to two years required for underground mine development. It is more amenable to selective mining than block caving where delusion may be up to 20 per cent. of the estimated grade. From the point of view of development cost, it is costlier. One of its great merits is that marginal ore during excavation can be mined and stacked separately for eventual extraction of its copper content. It requires the minimum number of skilled and semi-skilled workers and less exacting supervision. Amongst the favoured underground methods are block caving board and pillar method of openstopes and sub-level stoping with longholing.

Before concluding this note, it is necessary to deal with the water requirements. About three to five tons of water are requried per production of one ton of copper. Much of the water is usally reclaimed

and it is possible to do so, except in cases where mined oxide-sulphide ore is floated to give oxide and sulphide concentratas separately.

Tailing water is usually discharged, as at Miami, into a pond from where it is returned to the mill supply tank. At times, slimes are troublesome and a flocculent (Separan) is added in amounts of 0.003 lbs. per ton of ore. Phosphate is also added in amounts of one to two parts per million at key places where choking and scaling of pipelines have occurred. In the Nchanga mine. N. Rhodesia, where separate concentrates of oxides and sulphides are floated from a mixed ore, it is impossible to recover any of the ten million gallons of water from the tailings as the sodium hydrosulphide used in oxide flotation will bring oxides up with sulphides in subsequent treatment.

LONG RANGE ASPECTS OF COPPER DEVELOPMENT

The broad strategy of exploration for copper should take into account the immediate need for self-sufficiency as well as the long range requirements. Most of the prospects situated on the plains are marked by extensive old workings, dumps of mine wastes and slag heaps, which permit rapid preliminary appraisals to be carried out and proper choice of prospects to be made. Their easy accessibility facilitates, the rapid carrying out of proving operations and mines can be quickly brought into production as soon as proving operations result in positive conclusions. In Rajasthan, there are chances of finding large low-grade deposits which alone will permit self-sufficiency to be achieved within a short time. The prospects in Rajasthan, Singhbhum and other areas on the plains will, therefore, receive top priority in the matter of the proportion of the total exploratory work to be undertaken.

From the long range point of view, however, the Himalayan terrain is also very important. In the Himalayan terrain the present indications are that a large number of small but rich deposits will be found. These deposits, because of their mode of occurrence as well as the type of terrain in which they are found, will involve long drawn out programmes of exploration and proving. They may, however, be expected to make significant contributions to the total metal production, collectively, in course of time. They are also frequently of the multi-metal type, which increases their importance. When production from deposits in Singhbhum, Rajasthan, etc. reach the figure of

304,000 tonnes of metal, the potential resources in this area will begin to get depleted at a rapid rate.

The research aspect of the behaviour of the ore bodies in the different districts, the relationship to regional geology, the various types of controls in mineralisation that have been effective in localising ore, the relationship between ore formation and fundamental geological processes, such, as, tectonism, metamorphism and igneous phenomena, leaching, oxidation and secondary enrichment through the actions of meteoric water are extremely important. Geophysical and geochemical methods will prove extremely useful, provided the data obtained by them are interpreted in the light of sound geological knowledge of the terrain in which they are applied. Research studies for the purpose of understanding the presence and nature of metallogenetic epochs and provinces will have to be undertaken.

The precise significance of the observed spatial relationship between the distribution of particular elements and major geological features is being investigated. The above investigations are of great practical significance in two important respects. They greatly increase the scope of geochemical prospecting.

Vigorous attempts are being made to account for conformable replacement type of metaliferous deposits through a syngenetic mode of origin involving metamorphism of sedimentary rocks, into which the metals were introduced at the time of their formation. This subject is highly controversial at present, but is of considerable interest to all engaged in the search for ore.

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HOW INDIA CAN BE SELF-SUFFICIENT IN COPPER

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ABSTRACT

It is doubtful if any large indigenous sources of copper will be discovered in India early enough to meet the fast growing demand. Depths unattainable by the ancients must be reached and explored by modern methods, while areas buried under the alluvium and other material near old workings should be investigated by geophysical and geochemical methods followed by drilling. Continued study of improved methods of prospecting, mining and refining is necessary. Emergency demand may be met with by stock-piling. The metal should be conserved by substitution, scrap utilisation, recovery of secondary metal and restriction of domestic consumption.

India's mineral resources are vital to the welfare, progress and security of the nation.

Under the present mineral development policy, Government alone can undertake exploration for major mineral deposits, and the Ministry concerned receive the progress and final reports, maps, plans and sections from the experts it has engaged to undertake such operations.

Such reports, maps, etc., should be published before the information contained in them becomes out of date or incomplete and be of little assistance to interested parties.

Granting the over-riding authority of the State and its right to mine major minerals including oil, "atomic minerals", ferrous and non-ferrous ores, such as copper, lead and zinc, nothing can be lost by full publicity of the results of its investigations, and of the proposals for future work which have arisen from them. On the contrary, there is much to be gained. Criticism from outside experts can be most

helpful by drawing attention to points and views that may have been overlooked in preliminary researches.

Publication of scientific results is of a paramount importance, for it concerns the training of the students on whom the future industrial progress of the country depends. Without the fullest and latest information at their disposal teaching institutions are handicapped in their endeavours to impart advanced knowledge on Indian examples.

It is extremely doubtful whether large indigenous sources of supply will be discovered and explored early to meet our growing demands of copper. Efforts should be made, therefore, for the conservation of the metal by substitution, scrap utilisation, recovery of secondary metal, and by imposing restrictions on indiscriminate domestic consumption. Every effort should be made to use aluminium for copper, brass. etc., wherever possible. The production of aluminium should be increased. Stainless steel, other alloys, plastics and similar products may also be used to conserve copper in some of its applications.

The prospects of finding deposits of minerals containing precious metals or non-ferrous metals close to the surface with which the ancients were familiar may not be bright in easily accessible areas. The Himalayan region and parts of the Peninsula, which still require geological mapping on suitable scales, may hold promise of new finds. Intensive prospecting of the various recorded occurrences of copper-ores, particularly in the Singhbhum copper-belt, in Rajasthan, in the Sikkim-Darjeeling region, Gujarat (Chota Udaipur) etc. should be undertaken. Exploration should be carried out to sufficient depths where mining had not been made possible by the ancients on account of water trouble haulage, the prevailing low price of the metal and other technical and economic considerations. It is possible that small deposits or pockets of richer ore, capable of being hand-picked may repay mining and despatch to some appropriate centre or for smelting near Ghatsila for example by individual prospectors or groups of prospectors. Every encouragement should be given for the working of copper or similar ores and if necessary the rigidity of the mining rules should be relaxed. The gold mines of Kolar, the copper mines of Singhbum, the great

silver, lead, zinc and copper mines of Bawdwin and the tin and wolfram mines of Tennassarim in Burma all became profitable enterprises by the opening up in depth of the ancient workings.

In surveying the known occurrences of minerals, it is necessary to point out that geophysical and geochemical prospecting followed by drilling should be directed to gain more information on the reserves of ore from such areas where the ancients were not able to prospect.

For the conservation of the metal, a study of improved methods of prospecting, mining and refining of copper must be undertaken in close co-ordination with universities, research laboratories and mining organisations both in this country and abroad. The appointment of mineral attaches to the foreign embassies should also be considered, not only to keep India in touch with the technological advances of the foreign countries but also to gain knowledge on matters connected with mineral economics research.

A NOTE ON COPPER IN INDIA

BY

INDIAN NON-FERROUS METALS MANUFACTURERS' ASSOCIATION

ABSTRACT

The known occurrences of copper-ore are limited and cannot when developed meet more than 10 to 20 per cent. of the total Indian demand. Among the measures suggested to meet with the situation of self-sufficiency in copper are substitution of copper where possible by other metals, and efforts for prospecting and development of new deposits in private sector. The work of the Geological Survey of India and Indian Bureau of Mines should be expanded and facilities for foreign training for the technical personnel should be given.

INTRODUCTION

India is deficient in copper resources. The accelerated rate of Industrial development and the resultant export-import imbalance demand nevertheless that the availability of copper within the country should be increased, not by exercising some restraint on consumption, which is inconvenient to an economy in the developing stage. Besides this, the copper consumption at 182 grams per capita compares unfavourably even now with the corresponding figures for U.S.A., U.K., West Germany, Japan which are respectively 6·58, 9·4, 7·95 and 2·1 kg.

PRODUCTION

Production of copper in India is entirely by the Indian Copper Corporation, Ghatsila, who, up to 1955 were producing between 7,110 and 7,310 tonnes a year ; this has since been stepped up to around 8,000 tonnes per annum.

The reserves in the mines at the end of 1958 stood at 3·72 million tonnes of ore with 2·51 per cent. copper content.

The Geological Survey of India and the Indian Bureau of Mines have proved the following additional quantities of copper-ore :—

(i) Khetri (Rajasthan) ... 28·85 million tonnes of average 0·8 per cent. content in the Madhan-Kudhan Section.

(ii) Dariba Region (Rajasthan) ... 5 million tonnes of 2·5 per cent. copper.

The other deposits known to occur are in Almora (U.P.); Mamandur (Madras); near Morah (Manipur); along Kimin Ziro Road; Chota Dungar (Madhya Pradesh); Shumahal Area (Kashmir); Ramsu Area (Kashmir); Gani, Agnigundala (Andhra Pradesh). An electro-magnetic Survey, carried out several years ago by some German experts, had revealed the presence of copper in the Nellore region of Andhra Pradesh.

FUTURE DEVELOPMENT

The known reserves, even if developed fully, are not sufficient to meet the existing demands. The programmes presently in view are :—

(i)	Electrolytic Copper Refinery of the Indian Copper Corporation. ...	Capacity of 8,400 tonnes yearly, based on imported blister.
(ii)	Smelter of the National Mineral Development Corporation at Khetri. ...	10,000 tonnes of electrolytic copper per year to be stepped up later to 20,000 tonnes with technical collaboration of the Western Knapp Engineering Co. of the U.S.A.

DEMAND

As against these programmes, the requirements of copper are placed by the Association at 80,000 tonnes in 1960-61 and 1,45,000 tonnes in 1965-66. The Development Council for Non-ferrous Metals has in fact placed these respectively at 85,000 tonnes and 1,70,000 tonnes. The Association's own break up of consumption, industrywise, is as follows :-

Items		1961 (tonnes)	1966 (tonnes)
Cables and Conductors	...	30,000	52,500
Alloys and Castings	...	13,500	20,250
Brass and Copper sheets, Circles etc. (Commercial quality)	...	15,000	18,750
Brass and Copper sheets, rods, tubes, sections, wires etc. (Industrial quality)	...	10,000	25,000
Non-scheduled industry	...	5,000	6,250
DGSD, Railways and Govt.	...	5,000	20,000
Miscellaneous	...	1,500	2,250
		80,000	1,45,000

In fact, with the present controls on import and distribution, consumption is severely restrained although the non-scheduled sector of industry, it is felt, has been obtaining larger allocations of material. Further, the estimates of future demand in almost all major industrial products have been found under-rated. For these reasons, the higher consumption figures have been arrived at by the Development Council.

It has been assumed that aluminium is effectively substituting copper conductors. As far as insulated cables are concerned, the industry is known to be keen on evolving a phased programme of change over, consistent with the time required to adjust equipments and trained workers and to affect changes in accessories. In items like copper-based alloys, copper sulphate, rods, tubes, and other sections, however, substitution may not be possible. Subject to these, expansion programmes in regard to power generation, electrical machinery, transformers, electric motors, fans, etc. have been taken into account in arriving at the estimates.

FOREIGN EXCHANGE

During the Third Plan period (1961-66), the total consumption of copper, is placed at 6,62,500 tonnes in the form of pure metal. This is a litttle less than five times the yearly demand of 1,45,000 tonnes expected to be reached by 1966, because increases in consumption will be progressive and part of the reqirement will be met from scrap. This quantity of 1,45,000 tonnes of copper will cost approximately Rs. 200 crores, of which barely, Rs. 20 crores worth of metal may be available from indigenous sources. The rest of it indicates broadly the foreign exchange requirements. Copper prices, have varied cansiderably in the past, having touched the peak at about £436-10 per ton in international markets, with present prices at about £230 per long ton of electrolytic grade. As such, a precise estimate of the requirements of foreign exchange to import copper may be difficult.

SELF SUFFICIENCY

Even industrially advanced countries which produce substantial quantities of the metal are rarely able to avoid import of copper totally (See Appendix I) as the occurrences of the metal are unevenly distributed, and reserves are also limited.

Sir Ronald Praine, one of the world's authorities on copper, places world production of copper to be balancing with world consumption, there being no surplus.

With the limited ore reserves, however, self-sufficiency in copper in India seems to be a difficult proposition today. Among the many points to be taken into account in a programme of copper self-sufficiency will be :—

(1) Prospecting of known occurrences and proving of these to a workable stage, on a priority basis. As saving of foreign exchange is more of an emergent issue here than economics in cost, the stress must be on work that is rapidly processed, even if it proves slightly more expensive in the long run.

(2) Development of proved and workable reserves by the most effective and modern methods, wherever feasible, irrespective of whether such development takes place at the initiative of the public sector or the private sector.

(3) Adequate incentives to development.

(4) Substitution of copper, wherever technically feasible, without impairing competitive advantages of our products abroad or their efficiency at home..

(5) Import of copper, to the extent feasible, on barter basis.

(6) Development of Customs Smelters - even for fire refined copper.

(7) Copper conservation programme.

PROSPECTING

Prospecting work in the country is slow. It cannot be said that work has been tackled at the level of urgency that is required, by the Geological Survey of India, the Indian Bureau of Mines and other organisations. Occurrences which have been mapped out are also to be proved to a workable stage.

It has been estimated that from the mining to the metal stage, development of copper in other countries has involved investments of the order of £5ι0 to 550 per ton year which means that this work is costly and has to be accepted as such. In Peru, the figure is stated to have gone as high as $ 2,000 per ton year. Moreover, it needs

application of the most modern methods of survey as adopted by other countries to minimise the time spent on prospecting.

Association of parties in India and abroad, well conversant with techniques of prospecting and proving, with these programmes would be a worthwhile attempt to make, in the interest of more rapid results.

The position of prospecting in relation to the future working of the existing copper producing centres may be worth examining. Under conditions of deep mining with lodes barely 1.52 to 1.83 m. wide, it is difficult to work occurrences of 0.8 per cent. copper profitably, except those like Khetri deposits which are massive.

Further the present mining lease in Singhbhum copper belt extends to only 24 km. along the total 120 km. of the entire belt. In five years time therefore they will have reached the eastern boundary of the present lease and development thereafter appears an uncertain proposition.

The old Rakha mines area offers, from the prospecting point of view, the best assurance of obtaining copper-ore and it would be desirable to have the ore explored in detail as early as possible.

The Association would like to stress that in the anxiety to develop the new project at Khetri, the possibility of utilising the services of the existing producers of copper and of developing further an area where already some concrete work has been done, should not be ignored.

The senior personnel in the Geological Survey of India and the Indian Bureau of Mines should also be given opportunities to get conversant with the work done abroad.

METHODS

The 'development of proved ores', practicable at the initiative of the private sector, should not, be ruled out on consideration of policy. It is well known that most of the copper producing centres of the world are in the private sector and it is possible that if policy had allowed it, one of the important producers may have interested himself in the development of even Khetri on a collaborative basis with Indian capital.

INCENTIV

Incentives for copper production extended in other parts of the world have covered one or other of the following, singly or in combination :—

(i) Allowing prospecting and development expenditure as revenue expenditure to be charged against future profits.

(ii) Adequate provision, in providing depreciation allowances, for depletion of the ore reserves themselves.

(iii) Quick write off of the capital expenditure.

(iv) Tax holiday in the initial years to enable the mine to recover the capital costs of development and of installing processing equipments. Canada and South Africa extended such facilities to their gold mining industry and Rhodesia, to its copper mining industry 10 years ago.

Possibly where the State develops resources, with cost as a second consideration, the question of incentives may not be as important as in other parts of the world but incentives do figure where costs are taken into consideratian.

SUBSTITUTION

Substitution of copper however, should be the second important part of the copper development programme. The limits to substitution are set by technical feasibility, efficiency in performance ; and competitive advantages in overseas markets. In other words, there would be no point in substituting copper where such substitution proves inefficient or too costly on price even if it saves foreign exchange.

An important fact about copper is that the world's producers have never attempted to do active propaganda for expansion of its use, unlike in the case of zinc, aluminium, lead and nickel and therefore, it becomes apparent that copper is used today only for those purposes where it must be used.

Proposals for substitution have therefore to be governed by this background.

(a) The cable industry has already taken on hand actively the question of implementing Government's suggestions for using aluminium in place of copper. Excepting winding wires and strips, the economy measures would cover all cables and wires and the main approach is that while certain sizes and types of cables will continue to be manufactured in copper, others will be compulsorily switched over to aluminium. The manufacturers are formulating a programme of change over, which is expected to be finalised soon.

(b) There are, however, several other uses of copper as in alloys, coinage, utensils etc. where it could be substituted by aluminium or other metals very satisfactorily. To the extent also that metals other than copper, presently imported, could be substituted by any indigenously produced metal, the allocation of foreign exchange for copper could be maintained. For instance, the substitution of copper based alloys by aluminium alloys should be gone into in detail. To the extent, similarly, that we substitute aluminium or stainless steel for copper and brass in utensils, there is saving of copper in use.

Customs Smelters

The establishment of Customs Smelters or Smelters working on imported ores is another way of supplementing copper production. In doing this, some of the aspects to be considered are :—

(1) the kind of ore that will be available from abroad and whether it will be of uniform quality;

(2) will such ore supplies be reasonably uninterrupted ?

(3) will cost of ore and transportation costs and smelting and other treatment expenses in India work out appreciably lower than cost of equivalent finished metal ; if these were not to be lower, there is no reason why such production should not be subsidised for saving of exchange;

(4) what may be the basis of pricing such ore ?

(5) the extent to which stocks of ore have to be built up in the country.

Initially, it may cost more in actual importation and treating of ore, but Government should assist any such programme as they did in the case of aluminium and as they continue to do in the case of antimony. The establishment of a smelter for production of even fire refined copper could be considered, because there are many uses in which fire refined copper could serve, if these considerations were to be satisfactorily met with.

CONCLUSIONS

(1) The copper consumption will nearly double by 1965 but even at that level, the per capita consumption would be much lower than some of the industrialised countries of the world. This indicates that substitution should not be pressed too far in the present stage of development.

(2) The known occurrences of copper are limited and cannot when developed, meet more than 10 to 20 per cent. of the total Indian demand.

(3) Prospecting and proving should therefore be accelerated. The new deposits should be taken up for proving without further delay. If private industry is able to bring forward proposals to exploit proved ores, they should be encouraged to do so.

(4) Self-sufficiency in copper is not a practicable proposition. Therefore, while developing the copper deposits attempt should be made,

(a) to substitute other metals, where practicable, for copper,

(b) to develop metals as aluminium and manganese which may reduce import of items as nickel and make some foreign exchange available for import of additional copper ;

(c) to import to the extent feasible and to ensure that substitution is not carried to the point at which technical efficiency or competitive power of a product is impaired ;

(d) to facilitate, if warranted on considerations of foreign exchange, the establishment of Customs Smelters and to extend adequate incentive for this. Such smelters may be set up even for fire refined copper. The existing copper smelters could also be utilised as Customs Smelters.

5. In the prospecting and development of new deposits, the Private sector may be permitted to exploit the copper resources in this country, and development should not be exclusively limited to the Public sector. Private initiative should be able to secure the support and the assistance of some of the world's best producers of copper on favourable terms.

The existing copper producers may be permitted by the Govt. to extend their mining lease beyond their present areas and to carry out prospecting operations.

(6) Incentives to be given for development should be in keeping with the standards of other countries.

(7) The work of the Geological Survey of India and the Indian Bureau of Mines should be expanded by the employment of a larger number of qualified personnel and equipment, by affording facilities to such personnel to go abroad for advanced training in different aspects of the development programme and by placing at their disposal sufficient funds to enable the adoption of modern methods and techniques and equipment.

APPENDIX I

Production, Import and Consumption of Aluminium, Copper, Lead and Zinc in Different Countries in 1959.

1959—('000 Short tons)

Countries	ALUMINIUM			COPPER			LEAD			ZINC		
	Production	Imports	Consumption	Production	Imports	Consumption	Production	Imports	Consumption	Production	Imports	Consumption
U.S.A.	1953	195	2148	915	397	1312	364	308	672	858	76	934
Canada	599	—	89	374	—	130	135	—	49	255	—	66
W. Germany	167	128	295	311	174	485	212	45	257	200	95	295
France	191	—	185	31	176	207	97	57	154	160	25	185
Italy	83	5	88	—	124	124	50	17	67	81	—	70
Japan	110	12	122	214	27	241	71	17	88	176	—	171
U. K.	27	297	324	—	536	536	2	195	197	81	196	277
Australia	12	22	34	77	—	64	274	—	—	130	—	90
Belgian Congo	—	—	—	311	—	26*	—	—	24*	159	—	28*
N. Rhodesia	—	—	—	593	—		16	—		34	—	

* Total for Africa.

SELF-SUFFICIENCY IN COPPER

By

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ABSTRACT

Self-sufficiecy in copper is extremley desirable in view of the importance of this metal in strategy and in an expanding industrial economy. To achieve self sufficiency, it is necessary to carry out exploration and prospecting on the basis of regional geological structure and associated orogenic movements. More emphasis should be laid on geochemical and geophysical methods of prospecting that had hitherto been made possible. Special efforts should be made to employ experts trained in specialised branches.

INTRODUCTION

Self-sufficiency in copper, a metal of strategic importance, is very desirable ; it may eventually be attained in course of time, although it is debatable if it can be achieved so quickly as by the end of the Fourth Plan period, 1966-1971.

IMPORTANCE OF REGIONAL SURVEYS

Exploration of copper in India has hitherto been followed after following orthodox survey plans which lead us only up to a particular point and no further. Such exploration is dependant not merely upon the examination of local geology of circumscribed occurrences, but upon regional surveys based on detailed knowledge of geological structure and of the connected orogenic movements. It is only by obtaining a regional picture that one can establish which particular assemblage of geological factors gives rise to mineralisation. In other words instead of devoting attention mainly to the occurrences themselves, the fundamental causes of mineral genesis should be found out. The reports on the Almora copper belt and on minor occurrnces of

copper, zinc and lead in the Punjab and Himachal Pradesh often end with the recommendation that further exploration is necessary. The main reason for the inconclusiveness of these reports appears to be lack of proper equipment for exploration. Although steps for exploration are being taken to set the position right, the progress is albeit slow.

Geochemical and other methods of Exploration

Our methods of mineral prospecting seem to be a decade behind other countries. In order to expedite mineral production we should make much greater use of geochemical and geophysical methods, which, although initially expensive, become cheap tools for prospecting, besides the saving of a great deal of time.

Major Change in the Policy Required : Technical Personnel

During the last few years, Government has followed a policy of rapid recruitment of personnel in technical departments. Despite this satisfactory progress in exploration has not been made as by far a majority of those recruited are inexperienced. What makes the position worse is that even when experienced men are available, use is not made of them. Many young men who return after years of study abroad (and they include persons experienced in mineral exploration) do not find ready employment on reasonably good terms.

What is required is, therefore, a bold policy on the part of the Government which assures liberal terms of appointments to technical men who return to their country after 10 or 12 years of good work abroad.

SMELTING OF COPPER SULPHIDIC ORES AND RECOVERY OF SULPHUR

By

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ABSTRACT

The author refers to the mining and metallurgical practices now in vogue in Bihar and to the fact that the sulphurous gases produced during the course of smelting are allowed to escape. It is suggested that suitable steps should be taken to recover the sulphur.

The copper-ore mining and smelting of copper-ore for the extraction of the metal in this country were going on from ancient times. Mining was carried out in those days in a simple way and deep mining was not known. The copper smelting was being carried out by indigenous methods, utilising small hearths or furnaces in cottage industry pattern.

It is only during the thirties of this century that modern scientific methods of deep mining by driving shafts and utilisation of modern machinery for hoisting the ore minerals from underground have been adopted at Mosabani in Singhbhum district, Bihar and neighbouring areas. The modern metallurgical techniques by using reverberatory furnaces etc. have been followed in the only copper smelting factory at Moubhandar near Ghatsila, Bihar. This process of smelting has been in progress for the last 33 years but during the smelting operations no attempt has ever been made to recover the sulphur or sulphuric acid from the sulphidic ores during roasting. It may be mentioned here that India is very deficient in sulphur and the copper-ores of Singhbhum are sulphidic ores containing about 35% sulphur. In other words for every tonne of metallic copper produced about one tonne of sulphur goes out

in the smelter gases. If three lakh tonnes of copper-ore were produced annually then about one lakh tonnes of sulphur or about three lakh tonnes of sulphuric acid might have been produced. This amount of sulphur or sulphuric acid would have definitely met a substantial portion of the country's needs. The Indian Copper Corporation of Ghatsila has been producing about four lakh tonnes of copper sulphidic ores annually for smelting operations without any recovery of sulphur gases which could have been utilised for the manufacture of sulphuric acid, a very valuable and indispensible material for many industries.

It is, therefore, suggested that all concerned should take necessary and early steps to ensure that the valuable sulphurous gases from the roasters are not wasted but utilised to recover the sulphur contained in them.

Scientific methods of metallurgical extraction should really aim at the recovery of all possible substances from the ores. That will go a long way in achieving the conservation of mineral raw materials which are wasting assets of a nation. Once wasted such raw materials can never be replenished in future.

THE POSSIBILITY OF WORKING LOW GRADE COPPER-ORES IN INDIA

BY

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ABSTRACT

Hydrometallurgical treatment is suggested to process the low grade copper-ores for metal recovery in India. This treatment mainly consists of four operations in sequence namely, (1) concentration (2) Sulfatizing roast (3) leaching and purification (4) electrodeposition of copper from copper sulphate solution. With the advent of Fluo-Solids techniques in the field of roasting it is now possible to convert copper sulphide concentrates into water soluble copper sulphate under a sulfatizing roast successfully. This development has widened the scope of hydrometallurgical treatment so as to adopt as an economical and alternative process to pyrometallurgical method of treating copper sulphide concentrates. Chemical precipitation of copper from copper sulphate solution with sulphur dioxide gas deservcs to be investigated as a potential and cheap process for metal recovery.

INTRODUCTION

With the growing demand particularly of non-ferrous metals, such as copper, lead and zinc for further development of industrial establishments, the suitability of hydrometallurgical treatment, as an economical and alternative one, to the conventional and smelting techniques for processing the low grade copper ores, merits careful study.

METALLURGICAL TECHNIQUES

The metallurigical techniques, presently available to process the copper-ores can be broadly classified into two groups (1) Pyrometallurgical and (2) Hydrometallurgical. The latter inherently possesses the following advantages over the former:-

1. By electro-deposition, copper can be obtained directly in a very pure form.

2. Siliceous gangue is unaffected by most of the solvents whereas in pyrometallurgical process (smelter) this gangue must be slagged with relatively expensive fluxes.

3. It is necessary to use large amounts of expensive coke to furnish heat to promote reactions and melt the copper matte and slag. In contrast to this, hydrometallurgical processes are carried out at room temperature or at relatively low temperatures.

4. The handling of the products by pumps, pipes and conveyers is much easier and cheaper than handling molten matte, slags and blister copper etc. as in smelters.

5. The recovery of metal is usually higher than that obtained by smelting.

6. Ores of lower grade can be worked economically.

However, in spite of the aforesaid advantages in hydrometallurgical practice, pyrometallurgical techniques for treating copper-ores, specially sulphide ores are predominant all over the world. Only five or six plants are working on hydrometallurgical techniques to process the copper-ores. This phenomenon may be explained by two principal causes *viz.* (1) lack of roasting appliances hitherto, having precise control over the temparature and other roasting conditions (2) lack of suitable and cheap solvents for ores, specially for copper sulphide ores. Perhaps lack of cheap electric power and adequate supply of water also might be the additional causes in certain cases. With the advent of Fluo-Solids techniques in the field of roasting, the main drawback in roasting has been eliminated. It is now possible to treat sulphide copper floatation concentrates in such a way as to render 95 per cent. copper water soluble and 99.5 per cent. copper soluble in dilute sulphuric acid by careful control of Fluo-solids reactor. This development makes it economically possible to consider roasting, leaching and electrolysis as an alternative method for handling sulphide copper concentrates as against the conventional smelting process.

Therefore, it is considered that hydrometallurgical treatment may be economical to process low grade copper-ores, provided cheap electric power and plenty of water supply are available. In such a case the following operatians and processes in sequence will be the main features in hydrometallurgical treatment.

1. Concentration of the ores.
2. Sulfatizing roast of concentrates.
3. Leaching of calcines with water.
4. Electrodeposition of copper from copper sulphate solution.

1. Concentration

This unit operation is usually not found in existing plants treating low grade copper-oxide ores by wet methods, mainly because of the non-availability of cheap and suitable solvent, like weak sulphuric acid. However, in case of sulphide ores, due to lack of cheap and suitable solvents, these are to be converted into oxides or sulphates by roasting, before leaching with weak sulphuric acid or water. It will also be helpful to cut down the expenses in subsequent operation roasting.

Concentration has remarkable effects in the operational efficiency of leaching and electrolytic sections as evidenced by the observations made at Katanga leaching plant. These are given below :—

"Consumption of acid was reduced from 638 to 244 kg. per ton of copper. Recovery of coppet was raised from 85.8 per cent. to 93.6 per cent. Leaching extraction was 98.4 per cent. as against 96.4 per cent. Loss in entrained solution reduced to 4.72 per cent. as compared with 10.59 per cent.

Electrolytic results were also good. Ampere efficiency was raised from 78.97 to 93.67 per cent. largely due to less ferric iron in solution (1.66 gpl as against 6.36 gpl). In spite of the increased current density, the energy efficiency was raised from 47.34 to 48.67 per cent. Pregnant and spent solutions assayed 63.98 per cent. and 33.06 gpl of copper respectively as against the previous averages of 37.54 and 22.0 gpl. The acidity of the spent electrolyte was 54.5 as compared with 34.96 gpl." (Van Arsdele, p. 150).

As regards the beneficiation of sulphide ores, these can be easily concentrated by well established froth flotation techniques. Encouraging results were obtained in the laboratories of the Indian

Bureau of Mines on concentration tests of Khetri copper ore. In one of the tests, (Pradhan and Pillai) concentrates assayed 27.72 per cent copper with a recovery of 87.3 per cent. Total sulphur in concentrates assayed 34.51 per cent. Thus, this operation does not involve any difficulty.

2. Sulfatizing roast

Concentrates will be subjected to sulfatizing roast in Fluo-Solids reactor. Sulfatizing roast differs from an oxidizing one in that copper sulphate will be formed directly from sulphides. Simplified basic reactions for the behaviour of copper sulphides in oxidizing and sulfatizing atmosphere can be summarised as follows :

In oxidizing roast :

$$Cu_2S + 3O = Cu_2O + SO_2 \quad \ldots \quad (1)$$

$$Cu_2S + 4O = 2CuO + SO_2 \quad \ldots \quad (2)$$

$$CuS + 3O = CuO + SO_2 \quad \ldots \quad (3)$$

In sulfatizing roast :

$$Cu_2S + 5O = CuO + CuSO_4 \quad (4)$$

Reaction (4) indicates that a considerable excess of air is required to produce a high concentration of sulphate in the calcine. Copper sulphate can also form in the manner given below :

$$Cu_2S + 2O_2 = 2CuO + SO_2$$

$$2SO_2 + O_2 = 2SO_3$$

$$CuO + SO_3 = CuSO_4$$

The trioxide is formed by catalysis from SO_2 by iron oxides. That is why the presence of iron sulphides helps to produee more sulphate. Iron sulpaate is also formed in a similar way as copper sulphate. But the energetic decomposition of iron sulphate is at 480°C and of copper sulphate at 670°C (Halfman and Wanjukov, p. 523). Taking advantages of this difference in decomposition temperatures, it is theoretically possible to avoid the formation of iron sulphates under precise control of temperature.

On the above principle large scale tests run by Phelps Dodge corporation at Douglas, Arizona in Muffled type of wedge furnace have shown that only 60 to 80 per cent. copper in sulphide ore was converted into water soluble form because of the lack of precise control of the temperature. However, with the advent of Fluo-Solids roasting techniques it is now possible to render 95 per cent. copper water-soluble and 99.5 per cent. copper soluble in weak sulphuric acid from copper sulphide concentrates.

Fluo-Solids Technique: It was originally developed during second world war as a fluid catalyst process for cracking petroleum fractions by Standard oil development company. This was licensed to Dorr Co. for use in roasting and calcining fields. Since then they are pioneers in applying Fluo-Solids techniques to roasting. They developed Fluo-Solids reactor for roasting ores. The results of sulfatizing roast of a copper concentrate in that Fluo-Solids reactor, reproduced below :—
(Counselman 1951)

Fluo-Solids Roasting oj a Copper Concentrate

		Percentage		Percentage
Feed	Cu	22·1	Overflow wt.	71·7
Feed	Fe	33·6	Carry over wt.	28·3
Total	S	37·2	Gas Strength SO_2	5.2
Soluble	S	0·2	Gas Strength O_2	6·2

Roasting temperature : 725°C.
Overall solubilities :
Water soluble copper—89·0 per cent.
Weak acid soluble Copper—95·4 per cent.

This was designed on the well known principle that in a rising stream of air or gas a bed of solid particles in a reactor expands gradually in volume and attains the fluid state at a certain velocity of stream and this phenomenon is called *Fluidization.* In this state the bed behaves as if it is a column of fluid.

It offers maximum air-solid contact and heat transfer. A precision of control over roastiag conditions hitherto unknown is established. Flotation concentrates size is the best for feeding. Capacities are of the order of two to three sq. ft of reactor area per dry ton of concen-

trates (20 per cent. Sulphur) per day. (T. B. counselman) Power consumption is greater than in other types of roasting equipment. Fuel, either oil or coal can be added with the air if needed. If the product being roasted has at least about 12 per cent. sulphur the combustion will be self burning. 16 to 18 per cent. sulphur in a slurry feed is the minimum to make the charge self burning. Fuel costs, therefore, will be very low.

In 1957, Pilot studies were conducted at Bagdad Copper Co. Arizona, on a five-ton per day Pilot plant with the object of producing eletrolytic copper from Sulphide concentrates. (Mineral World, P. 503) Concentrates were subjected to sulphatizing roast in Dorr Co. Fluo-Solids reactor. Calcines were subsequently leached and copper recovered from pregnant solution by electrolytic process. Normal cathodes assaying over 99.9 per cent. copper have been produced.

3. Leaching and Purification

Calcines, containing mainly copper sulphate and oxides of iron, can be leached with water by counter current decantation (C. C. D) and the residue can be separated with Moore filters. Purification of leach solution is an important step in the sense that operational efficiency and purity of the product by electrolysis depends considerably on this operation. The methods of purification differ as per the impurities present in solution, which vary from ore to ore, from deposit to deposit and some times from vein to vein. However, standard purification techniques on iudustrial scale have been developed to eliminate the impurities.

4. Precipitation of copper from solution

This can be done by electrolysis as well as by chemical precipitation.

Electrodeposition : Electrolytic precipitation on industrial scale has been well developed. The underlying principle is that an electrolyte of a metal such as purified leach solution begins to decompose when a voltage applied to it through suitable electrodes reaches a definite point called the decomposition voltage. For each metal there

is a definite decomposition voltage which varies according to the position in the *e.m.f.* series. The decomposition voltage of copper sulphate is 1. 19.

Pure copper as cathode and antimonial lead as anode are used. Graphite anodes are also used in some plants but quick disintegration of cathode is observed. Much of the operational and equipment details of electrolytic plants can be procured from the existing firms such as Inspiration Consolidated Co, and Chile Exploration Corporation.

Electrolytic plant is an expensive installation, power cost in electrolysis being usually a substantial part of the total operating cost. So the scale of operation is an important factor so as to enable the operating cost for the copper produced in this type of plants to be kept at a reasonable level. Current losses likely to occur in leakages, electrode short circuiting and due to polarisation etc. must be kept to the minimum. Normally one kwh. of power is required to deposit 363 grams. of copper.

Chemical Precipitation of Copper : If the copper sulphate solution is saturated with sulphur dioxide and then heated under pressure, a part of the copper can be precipitated as metallic copper, probably according to the following equation :

$$CuSO_4 + SO_2 + 2H_2O = Cu + 2H_2SO_4$$

On the above principle, using a 10 per cent. solution of copper sulphate and heating to about 100° C at a pressure of about 50 lb/sq. inch, about half of the copper is precipitated as metal accompanied by the production of free sulphuric acid.

This method has potential and attractive features where sulphur dioxide is available, and may be considered where copper sulphide concentrates are subjected to sulfatizing roast, as outlined in the above process. From such a roast sulphur dioxide gas for saturation and waste heat for heating would be available. It would, however, be applicable to small scale operations. The purity of the precipitated copper would be compared favourably with electrolytic one. However much more research work has to be conducted before it can be commercialised.

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COPPER : AN OUTLOOK FOR FUTURE DISCOVERIES AND PRODUCTION IN INDIA

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ABSTRACT

In India copper has been recovered from its ores and used since the earliest known historical times. Presently, the best results on the exploration of copper can be expected by the more intense exploitation of the known areas and increasing their known resources by concentrated applications of all available methods of mineral exploration. To meet the requirements of copper in the country, an active policy to recover scrap copper and brass from the non-industrial articles like household utensils etc., may be aimed.

From the study of world production of copper over several years and the estimated resources available in the chief producing areas, it is indicated that India can meet only about 10 per cent. of her requirements of copper from domestic production.

Although copper is widespread in nature, and traces are known from almost all rock types, major resources occur only in a few places. From available records, it is noted that only about 18 countries produce copper at the rate of over 10,160 tonnes a year, while another 18 countries also recorded some output, but about 90 per cent. of the world's copper production comes from only four regions, namely, Chile, Africa, Canada and USSR, leaving only seven per cent. in other countries.

Besides the known producers of the metal, since 1900, only Chile and Africa (Belgian Congo-Northern Rhodesia) have become important producers with phenomenal discoveries and resources. These facts are relevant in connection with the search for new copper deposits in India.

Copper has been recovered from its ores and used in India since the earliest known historical times. The innumerable old workings, some of huge dimensions and slag heaps accompanying them,

are records of the ancient mining activity. In fact it can be said that the search for old copper workings is the beginning of the exploration for copper in India today.

It would seem, therefore, that a large proportion of the copper-ore deposits have already been discovered, and often worked to the limit possible in those times; finding any other deposits remaining concealed or poorly exposed, will be a relatively slow process.

Accepting that India is a fully explored country as far as copper is concerned, the best results can be expected by the more intense exploitation of the known areas and increasing their known resources by concentrated application of all available methods of mineral exploration.

During the last ten or eleven years the search for new copper-ore deposits has been actively pursued in India. Naturally enough the Singhbhum belt in Bihar and the Khetri area in Rajasthan were the first to be tackled. In Khetri an ore body has been located, and estimated to contain about 28.44 million tonnes of the ore of grade between 0.8 and 2.5 per cent copper, (203,200 tonnes recoverable copper) and recently in Singhbhum an ore body has been struck, and a preliminary estimate would suggest that it might be able to sustain a production similar to that of the present Mosaboni mines.

Intensive work in potentially promising areas has thus already delineated two regions where there are fair prospects of opening up mines capable of producing copper at the rate of about 10-15,000 tonnes per year. Experienced personnel should be deputed to work in these areas, and the highest priority should be given to the project. Large-scale mapping should be followed up by intensive prospecting, and drilling if necessary. Plans should be ready to exploit quickly any ore body located.

In the Almora, Pithorgarh and Garhwal districts in the Himalayas and in the Andhra Pradesh, several copper shows and old workings are being (1962) investigated in detail. In the Almora and Pithorgarh districts, results so far are discouraging ; other Himalayan prospects as

in Garhwal might turn out to be similar since the type and environments of the copper shows are alike. As such these areas will be given only a low priority in the use of personnel and equipment for necessary investigations for the present, but geological study should be pursued and the more promising spots should be marked for intensive prospecting in the future.

The production of copper in India from the Singhbhum region has been running at about 0.3 per cent of world production for the last 30 years or so. The total world production of copper since 1925 is of the order of 86-91 million tonnes of which the Indian share of about 203,000 tonnes comes to about 0.2 per cent. During this period the reserves of the world have been considerably augmented by the proving of huge copper deposits in the Belgian Congo-Northern Rhodesia area in Africa. A total of about 102 million tonnes of copper has been estimated to be the world reserves available as per present knowledge.

The current rate of production of copper for the world is over 4.6 million tonnes, showing an increase of about 50 per cent since 1950. At least a similar increase can be expected during the next ten years, reaching about 6.1 million tonnes by 1970.

Production in India from the Indian Copper Corporation mines in Singhbhum has increased only about 30 per cent since 1950 to just over 9,100 tonnes in 1961. This might be expected to increase to 12,000—13,000 tonnes by 1966.

In the U. S. A. and the industrialised countries of Western Europe about 15 to 20 per cent of domestic requirements of copper are met from scrap. Although India imports a part of her requirements of the metal as scrap, no active policy is evident to recover scrap copper and brass from non-industrial articles like household utensils. A rough estimate suggests that about 250,403 tonnes of copper and brass must be available in the country. It might be possible to recover about 50 per cent of this ; a recovery rate of about 10,000 tonnes a year may be aimed at through a considered programme of search and collection. If this is possible, this amount of copper could be procured internally and a saving in foreign exchange effected.

Summarising, that a study of world production of copper over several years, together with current rate and future expected rates of

production and the estimated resources available in the chief producing areas, indicates that India can meet only a small part—about 10 per cent of her requirements of copper from domestic production for several years to come, unless some large deposits are discovered in the future; but such great discoveries cannot reasonably be expected in this country which appears to have been thoroughly explored with respect to copper-ores.

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POTENTIALITIES OF COPPER DEPOSITS IN SOUTHERN INDIA

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ABSTRACT

The known copper occurrences of Southern India are located at Gani-Kalava, Agnigundala, Garimanipenta, Mailaram-Yellambailu, Chitaldrug, Kalyadi and Mamandur in Andhra, Mysore and Madras States. These deposits are localised in Archaean gneisses and amphibolites, Dharwar schists and Cuddapah formations.

Detailed mapping and study of the deposits have indicated that the deposits associated with the younger Cuddapah rocks (Gani-Kalava and Agnigundala) are of larger magnitude and intensity. The deposits in Dharwar schists of Mysore and Nellore (Chitaldrug, Kalyadi and Garimanipenta) are of limited strike length and intensity. Those associated with Archaean gneisses (Mamandur and main Garimanipenta) are of the nature of impersistent lenses of limited strike length and of doubtful economic value.

INTRODUCTION

The known occurrances of copper in Southern India are at Gani (15°40′ : 78°19′)-Kalava(15°37′ : 78°12′), Agnigundala (16°11′ : 79°45′) Garimanipenta (14°59′ : 79°32′) and Mailaram (17°43′ : 80°37′) Yellambailu (17°41′ : 80°40′) in Andhra Pradesh ; at Chitaldrug, Kalyadi (13°14′ : 76°09′) and Hadabanatta (11°57′ : 77°19′) in Mysore ; and at Mamandur (12°00′ : 79°00′) in Madras. In the light of the results of the investigations carried out during the period 1958 to 1961 as part of the programme under the Base Metal Unit of the Geological Survey of India, the potentialities of these depcsits are presented in the paper. The investigations include detailed structural mapping, geochemical prospecting and in a few cases pitting, trenching and preliminary exploratory drilling.

GEOLOGY

The copper deposits of Southern India are associated with Pre-Cambrian crystalline and metamorphic rocks and unfossiliferous Purana sediments. The deposits at Gani-Kalava in Kurnool district and Agnigundala in Guntur District of Andhra Pradesh are localised in Cuddapah-Kurnool formations while that at Mailaram-Yellambailu in Khammamet district is found in rocks of the Pakhal Series (? Cuddapah). The deposits at Ingladahal in Chitaldrug district and Kalyadi in Hassan district of Mysore and the few scattered small occurrences in the Garimanipenta area of Nellore district, Andhra Pradesh, are localised in Dharwar schists and associated quartzites. The main Garimanipenta deposits, and the Mamandur deposits in the South Arcot district of Madras, as well as the occurrences at Hadabanatta in the Kollegal *taluk* of Mysore, are localised in Archaean gneisses and associated amphibolites, etc.

All these deposits are found in association with hydro-thermal quartz-vein zones of varying degrees of intensity and grades, localised generally along stratigraphic contacts of certain competent lithological units in areas of intense deformation and granitic intrusions.

The intensive mapping and study of the deposits have indicated that—

(1) the deposits at Gani-Kalava and Agnigundala, associated with the younger Cuddapah-Kurnool rocks, are of larger magnitude and show promising prospects in the adjacent areas.

(2) the deposits e. g. the Kalyadi, Chitaldrug and Garimanipenta belts, associated with the next older formations, in the Dharwar schists are of limited strike length and possibly of limited economic value.

(3) the deposits e. g. the main Garimanipenta belt associated with the oldest rock formations *viz*. the Archaean gneisses, amphibolites and other rocks, are of the nature of impersistent lenses and stringers of very limited strike length and depth extension, and of doubtful economic value. The only exception to this is the deposit at Mamandur, where a small

strike length of fairly rich multi-metal copper-lead-zinc mineralisation has been struck, which may prove to be of value as a sizeable economic deposit for a small scale prospect.

ANCIENT WORKINGS

All the deposits mentioned above are marked by ancient workings belonging to the period of Tippu Sultan or Vijayanagar Kingdom, probably dating back to the 15th century. The most extensive and deepest ancient workings appear to be in the Agnigundala belt. The size of these workings, old mine dumps and the presence of even ancient tailings in the dumps slag heaps, remains of earthen retorts and furnaces and occasional pieces of metallic lead picked up from the fields, suggest that there must have been a thriving copper and lead smelting industry at Agnigundala. Similar, but less extensive and smaller workings, are present at Gani-Kalave and Kalyadi. The ancient workings at Garimanipenta, Chitaldrug and Mamandur (apart from a few large more modern workings at Chitaldrug) are the least promising, either because the rich surface indications of oxidised ore did not persist in depth and were less profitable, or because the ancients were not clever enough to pursue the ore bodies in depth.

DESCRIPTION OF VARIOUS COPPER BELTS

The Gani-Kalava, Agnigundala, Garimanipenta and Kalyadi and Mamandur deposits have been under active investigations in recent years and have been dealt with separately elsewhere in this volume.

Besides the above, the following occurrences of copper-ore in the south also deserve a mention.

1. Mailaram-Yellambailu Copper Occurrences, Khammamett district

Considerable prospecting, including drilling exploration, has been carried out in the past at Yellambailu by the students and staff of the Andhra University in collaboration with the Kottagudem Collieries Co., and at Mailaram by M/s. John Taylor & Sons of the Kolar Gold Fields. The main occurrences in this area are at Mailaram, Yellambailu and Sarakal to the north-east of Kottagudem

collieries. Detailed mapping of the deposits and evaluation of the previous prospecting operations, as well as geophysical survey conducted recently by the Geological Survey of India, indicate that the occurrences are of disseminated type in quartz veins within the phyllites, schists, limestones aud quartzites of the Pakhal series. The deposits appear to have very limited strike extension and are not very encouraging. Geophysical investigations have indicated the presence of some anomalies which are of a low order. It may, therefore, be worthwhile to put down a few shallow angular drill holes to check and confirm the potentialities of these deposits, and to make a thorough search in the surrounding area for gossan and other signs of appreciable mineralisation.

2. Copper Occurrences in Ingladahal Pyrite Belt, Chitaldrug district.

There are several small ancient workings for copper on the western flank of Belligudda hill and to the north and north-west of Ingladahal. An old adit and a few pits recently dug are found on the western flank of Belligudda hill. The main occurrences of these ancient prospects are those N.N.W. of Kunchiganahalu, north-eastern flanks of Jogimaradi hill and on the western flank of Belligudda hill to the west of pyrite prospects, where the mineralisation has been traced in two parallel zones extending for a strike length of 450m. The mineralisation is mostly found in ferruginous chert band and associated vein-quartz in foliated greenstone. Considering the size of the old workings, it is doubtful whether these occurrences can be of economic importance. However, a few shallow inclined drill holes may be put down to test the nature of copper mineralisation and its tenor and possible economic workability.

3. Copper Occurrence in Hadabanatta gold mine, Kollegal Taluk.

A high analytical value of copper at 3 per cent. was previously reported by Hayden from Hadabanatta gold mine possibly from the 15-20 cm. thick, gossanised malachite-rich casing on the hanging wall of a 1.5 to 1.8 m. thick auriferous quartz reef at the entrance to the inclined shaft of the old mine. Recent resampling of both the quartz

and gossan zone by the present author, however did not show appreciable copper or even gold values, and the gossanised casing could not be traced for any great distance down-dip in the shaft. It thus appears, that there is no prominent vein of copper-ore of any appreciable thickness in this area.

EVALUATION OF DEPOSITS

A critical study of the controls of mineralisation, strike persistence of the mineralised zones, intensity of ancient workings and other factors suggest that the deposits at Gani-Kalava and Agnigundala are the most prospective for locating economic ore bodies of immediate value. The Agnigundala area is the more promising out of the two, containing both copper and lead and should, therefore, be pursued by a programme of intensive drilling exploration on high priority. Drilling to shallower depths in Gani-Kalava area has indicated good thickness (1.0 to 3.0m.) of lodes of appreciable copper content (1.00 to 2.74 per cent.), although these lodes are found to be rather lenticular and their continuity along the strike or in the shallower depths explored so far has not been established. But the great thickness of the Cuddapah rocks here and the probable occurrence at depth of lithological horizons like quartzites and limestones which are more favourable for richer mineralisation, warrant deep drilling in this area.

Finally, in the deposit at Mamandur in South Arcot district, detailed mapping and trenching has shown gossan bands and veins of sphalerite together with disseminations of galena and chalcopyrite. The zone is, however, traceable only for a strike length of about 415 m., with widths ranging from 1.5 to 12.0m., two drill holes so far completed, have confirmed the multi-metal nature of the mineralisation. The first hole revealed the presence of 0.3 m. lode averaging 7 per cent. zinc, 10 per cent. lead and 0.5 per cent copper, but the second hole just completed (and not yet assayed) has shown richer copper mineralisation. In view of the multi-metal nature of the mineralisation there is some hope of finding ore of economic grade, though the reserves will depend on the depth extension of the ore-body.

CONCLUSIONS

It may be seen that the copper deposits of Southern India are of smaller dimension and of limited economic potentiality in comparison with the larger deposits in Singhbhum, Rajasthan and other places. The deposits at Agnigundala, Gani-Kalava, South Arcot and Kalyadi appear to be fairly promising as sizeable economic units for small scale production to supplement the country's future requirements of copper. It is likely that the Agnigundala deposit and the multi-metal Mamandur occurrence might prove to be larger than anticipated. A systematic programme of drilling followed by exploratory mining and metallurgical tests is needed.

Acknowledgements

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COPPER-LEAD DEPOSITS OF AGNIGUNDALA, GUNTUR DISTRICT, ANDHRA PRADESH

By

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(With Plates 1—2)

ABSTRACT

The copper-lead deposits of Agnigundala area in Guntur district of Andhra Pradesh are localised within highly folded upper Cuddapah rocks. There are four main groups of deposits in Dhukonda, Nallakonda, Bandalamottu and Peddagavalkonda, having a total strike length of nearly five kilometres. The deposits are of hydrothermal origin and are controlled by structural, stratigraphic and lithologic factors. The copper deposits are localised as overlapping, parallel, *en echelon* lenses between quartzites and phyllites, whereas the lead deposits are of the nature of "pitches and flats" in the dolomitic formation.

The deposits have been worked by the ancients in the past as indicated from numerous old workings, slag heaps, etc. Surface indications and other geological features suggest that they are very likely to be of commercial importance for copper and lead.

INTRODUCTION

The mineralised belt near Agnigundala is about 20 km. from Vinukonda, one of the *taluk* headquarters in Guntur district, Andhra Pradesh. The ore deposits occur in the Cuddapah formations along a range of hills trending N.E.—S.W. and running diagonally across the area.

Ancient Mining and Metallurgy

The occurrence of copper and lead-ore deposits near Agnigundala along a narrow belt of three kilometres has been known for a very long time. The earliest published reference to the existence of old workings has been made by Heyne (1814).

The old workings are of the nature of long open trenches following the lodes along their strike and have reached depths of

30 m. or more in the direction of the dip. Mining was carried out by opencast method and irregular underground workings. The margins of these old workings are generally characterised by fairly large dumps of waste rock which appears to have come from the foot-wall and hanging wall of the workings in the course of stoping. Crushing of ore appears to have been done in two stages using small boulders of fine-grained quartzite and dolerite dyke, the first consisting of a preliminary breaking down and separation of the coarse particles from the fines and the second consisting of further reduction of the finer materials. Near the old mining camp on the eastern side of Dhukonda, there is an extensive dump of coarse tailings. Within the latter, small washing tanks of different shapes and sizes are seen.

Evidences of ancient smelting activity are also seen by the presence of slag dumps around Agnigundala (i) about 335 m. (five furlongs) east of Ipur, (ii) between Errapalem and Vudjerla, and (iii) 134 m. (two furlongs) east of Malapadu. The dumps also contain numerous broken tube-like bodies believed to be the broken earthen crucibles or cupolas. These tubes are seen in all the dumps but actual furnaces are seen only near Ipur. The furnaces are made up of ordinary potter's clay and are somewhat pear shaped, the longer axis being horizontal.

GEOLOGY

The first appraisal of the geology of this area was made by King (1872) in his memoir on the Cuddapah basin. The rocks of the mineralised zone were included by him under the Nallamalai series of upper Cuddapahs, which are folded, faulted and slightly metamorphosed. The mineralisation occurs parallel to the eastern margin of the Cuddapah basin and is related to the tectonics of the area (Pl. 1).

The Archaeans, the oldest rocks of the region, are represented by metamorphic rocks like biotite-schist and gneisses, amphibolite, etc. In addition, coarse-grained granites, trap and dolerite dykes are also found. The Archaeans are unconformably overlain by the rocks of the Nallamalai series, which is divided into two stages (1) Bairenkonda quartzite (?) and (2) Cumbum slates (Pl. 1). The Bairenkonda stage comprises grey, fine-grained and compact quartzites. The Cumbum

slates include argillite, slates, chlorite and sericite-phyllites, interbedded with fine to medium and coarse-grained quartzites as well as dolomites and limestones.

The rocks of the area are folded, faulted, sheared and highly disturbed. The stratigraphy of the area has, therefore, been deduced from the structural elements like bedding-cleavage relationship, drag fold patterns, lineations and other sedimentary structures like original trace of bedding, graded bedding and current bedding. The Bairenkonda quartzite is overlain by chlorite-phyllite which becomes gradually calcareous in its upper horizons. The calcareous phyllite, in many places, passes into grey limestone and again to chlorite-phyllite. The chlorite-phyllite is succeeded by dolomite beds of varying thickness in different places, and is mineralised in the Dhukonda area.

The dolomite beds are succeeded by another set of chlorite-phyllites and later by fine to coarse-grained quartzites. This quartzite horizon is in some places intimately associated with a thin bed of dolomite, which is found to be mineralised in the Nallakonda and Dhukonda localities and further north in the Borrakonda and intermittently up to Rechelakonda.

Regional structure

In the central part of the area the rocks have been intensely folded into overturned isoclinal folds along N. E.-S. W. axes and are, in some places very tightly drag folded, overturned, and thrust against the Archaean gneisses. The most important features are the three dome structures formed by coarse-grained granites along the eastern margin of the Cuddapah basin (Pl. 2).

Folds: The Dhukonda deposit is located on the flank of a major syncline to the east and an anticline to the west plunging south at 30°. The axis of the anticline is along the centre of the valley between Dhukonda-Lingalakonda-Borrakonda-Rechelakonda and Suddimottukonda-Kandanalekonda hill ranges. To the east of this major anticline, a complimentary syncline is noticed in the small group of hills .473 and 644. N.N.W. and north of Vudjerla respectively. Further eastward the Cuddapah formations are seen to be eroded, exposing the Ipur dome structure. To the west of the major anticline the rocks are folded into a broad syncline plunging south at 30° and extending right up to the western part of the area.

The rocks in the north-western part of the area do not seem to be much disturbed and the strata are all gently dipping to the east. On the other hand, in the north-eastern corner of the area, the rocks are folded into anticlines and synclines, the westernmost anticline being the easterly continuation of the major anticline mentioned in the central part of the area. From the available sedimentary criteria of tops and bottoms, the other folds in this part of the area appear to be overturned. No definite indications about the plunge of the folds are noticed and it is presumed that they 'are non-plunging folds with horizontal axes.

The dominant structure in the southern part of the area is the Vellaturu dome having a northerly plunge, north of the dome and southerly plunge, south of the dome with its axis trending N.E.—S.W. On the eastern flank of the Vellaturu dome the Cuddapah rocks are folded into minor anticlines and synclines as seen from the repetitions of Bairenkonda quartzites and rocks of the Cumbum stage. As the country, west of the Vellaturu dome was not geologically mapped, it was not possible to determine the exact nature of the structure in the south-western part of the area.

Faul s : A few faults of small magnitude are, however, observed in the Bairenkonda quartzites flanking the Vellaturu dome.

Shear fractures and zones : Shearing of rocks is a common feature. The shear zones are parallel to the general foliation of the rocks and are brought out prominently by silicification or subsequent intrusion of quartz veins and stringers.

It is noted that in the phyllites, chlorite has recrystallised and the rock is rendered more hard and compact, while a similar effect is also observed in the dolomitic formation. The dolomite is locally recrystallised to coarse crystalline aggregates. The effect of shearing in quartzite is the formation of gash veins, brecciation, etc.

COPPER AND LEAD-ORE MINERALISATION

No doubt the quartzite outcrops and the old working faces in Nallakonda area show considerable malachite stains, and the mineralised wall rock, when freshly exposed, reveals disseminations of chalco-

pyrite; but disseminated galena is also noticed in Dhukonda area. The old workings in the southern spur of Dhukonda, Bandalamottu and Peddaganalakonda mainly show galena. With regard to the genesis, the available evidences seem to indicate that the deposits are of hydrothermal epigenetic origin.

The two main deposits, where detailed geological mapping was carried out are :—

1. The Nallakonda Copper Deposit, and
2. Dhukonda Copper and Lead Deposit.

Nallakonda Copper Deposit

The Nallakonda copper deposit is about five kilometres north-west of Agnigundala and eight kilometres west of Ipur. According to the old reports it was in this area that mining was first started. The mineralisation in this area extends for about 630 m. as revealed by the intense malachite stains on the outcrops of the quartzites and on the walls of the old workings. Leached cappings of limonitic material are also present in the quartzites. The mineralisation is at the stratigraphic contact of coarse quartzites and phyllites, the latter forming the foot wall. The mineralisation is within the coarse quartzites for a width varying from about 1.5 to 3 metres from the contact of the phyllites. The contact is fractured and brecciated, providing channel-ways for the ore-bearing solutions, as also receptacles for the ore at the same time.

Thus the controls of mineralisation are partly stratigraphic, lithologic and structural. The alteration phases are easily recognised in all the deposits in the Agnigundala area. They are represented by silicification and sericitisation. The silicic replacement is strong along certain shear planes, faults and breccia zones in the vicinity of the old workings. The outcrops of quartzites are traversed by thin veins of white hydrothermal quartz in all directions. In some places, they are of the nature of gash veins while in other places they show *en echelon* pattern. Silicification is seen in the dolomite and the rock is, at places, traversed by numerous veinlets of quartz. In some places, there is developmeht of cryptocrystalline cherty quartz (jasperoid) possibly due to the replacement of the carbonate minerals.

Sericitisation is another common alteration recognised within the phyllites in the vicinity of the ore bodies. The foot walls of the

old workings are in most cases composed of silky white sericite-phyllite. The width of sericitised zone is not much, seldom exceeding 1.5 to 3 metres. Microsections of the rock show about 60 per cent of sericite in the foot wall phyllites.

Dhukonda Copper and Lead Deposits.

The Dhukonda area lies at a distance of about 6.5 km. west of Ipur and about 6.5 km. N. N. W. of Agnigundala. It is on the eastern flank of Dhukonda extending up to the southern spur of the hill. The mineralised portion is about 2.5 km. in length, of which 1.25 km. in the aggregate may make up as probable ore shoots.

The mineralisation here is near the stratigraphical contacts between quartzite and dolomite, between dolomite and phyllite, and between quartzite and phyllite. In the first two cases, mineralisation is mostly of lead, but where the mineralisation is confined to the quartzite -phyllite contact, it is predominantly of copper. Compared to the Nallakonda area, the fracturing and brecciation of the wall-rock quartzite is less in Dhukonda area although there is considerable tight folding of the beds which appear to be more intensely mineralised along parallel horizons.

The folds are of subsidiary nature and show both dextral and sinistral patterns, observable on both the flanks of the main fold, with the axis of the main fold parallel to those of the subsidiary folds. Both the main and subsidiary folds form a part of the major anticline in the regional structure. The plunge of the folds is fairly steep towards south-west.

The controls of mineralisation, as in the Nallakonda area are structural, stratigraphic and lithologic. The physical character of quartzite, namely its porosity, and the chemical affinity of the dolomite have played an important role in the formation of the ore deposit. In general, replacement has been dominant over fracture filling in the rocks and the mineralisation has taken place along the contact of two rock formations as in concordant ore bodies.

The hydrothermal alteration here is similar to that in the Nallakonda area but the intensity of silicification is much less. In addition to the alterations described in the Nallakonda area, kaolinisation of the phyllite is also noticed. The quartzites are silicified and

so are the phyllites and dolomites. Certain zones within the phyllites are intensely silicified, though there are no indications of their being mineralised.

Sampling of old tailing and slag heaps in the area

The old tailing dumps near the old workings at Dhukonda and the ancient slags from near Errapalem were sampled and assayed to find out their metal content. The tailings near Dhukonda old workings reveal appreciable percentage of lead and copper.

One specimen of lead metal collected from a field near Agnigundala (by the President of Agnigundala Panchayat Board) assayed 99.48 per cent lead and 0.22 per cent silver indicating a high degree of purity of the metal extracted by the ancient smelters.

GEOCHEMICAL SAMPLING

To determine the nature and extent of mineralisation outside the area of the old workings, geochemical soil sample survey was carried out in the dolomitic formation in Nallakonda and Dhukonda areas. In the former area, five geochemical lines were laid at intervals of about 90 metres across the strike of the dolomite formation and about 72 soil samples were collected and geochemically analysed for copper and lead. No appreciable metal values were found in the area. In Dhukonda area, seven geochemical lines were laid at intervals of 90-150 metres across the dolomitic zone and about 90 soil samples were collected and assayed for copper and lead. The samples from one of the lines gave some encouraging values for lead.

In view of the highly disturbed nature of the ground in the areas of old workings, no attempt was made to lay geochemical lines there; besides no reliable information could be obtained due to possible contamination from the dumps, etc.

SUMMARY

The occurrence of copper-ore near Agnigundala has been known for a very long time. Considering the existence of numerous old workings and the large slag dumps in the area, it appears that considerable quantity of ore had been mined and treated in the past. There is no published account to assess the extent of mining carried out and the reasons for the stoppage of work.

The present large-scale mapping of the area has revealed well-defined stratigraphic, lithologic and structural controls and the existence of hydrothermal alterations, like silicification, sericitisation, pyritisation and dolomitisation. These are generally considered as favourable indications for ore.

Mineralisation in Nallakonda area is exclusively in the quartzites and consists mainly of copper. Filling of pore spaces and fractures has been dominant over replacement. The structure of the ore bodies is of vein type.

On the other hand, mineralisation in Dhukonda area is partly in quartzites and partly in dolomites and consists of both copper and lead. Replacement seems to have been dominant over vein filling. Mineralisation is exclusively along the bedding planes and the structure of the ore bodies is mainly of concordant type.

The deposits mapped so far in Nallakonda and Dhukonda areas are likely to be of economic importance. Detailed exploration has to be carried out to study the nature, extent, thickness and general grade of the ore bodies and to assess their economic workability.

Acknowledgement

The authors express their grateful thanks to Shri S. Narayanaswamy under whose guidance this investigation has been carried out and to Dr. A. G. Jhingran for many valuable suggestions.

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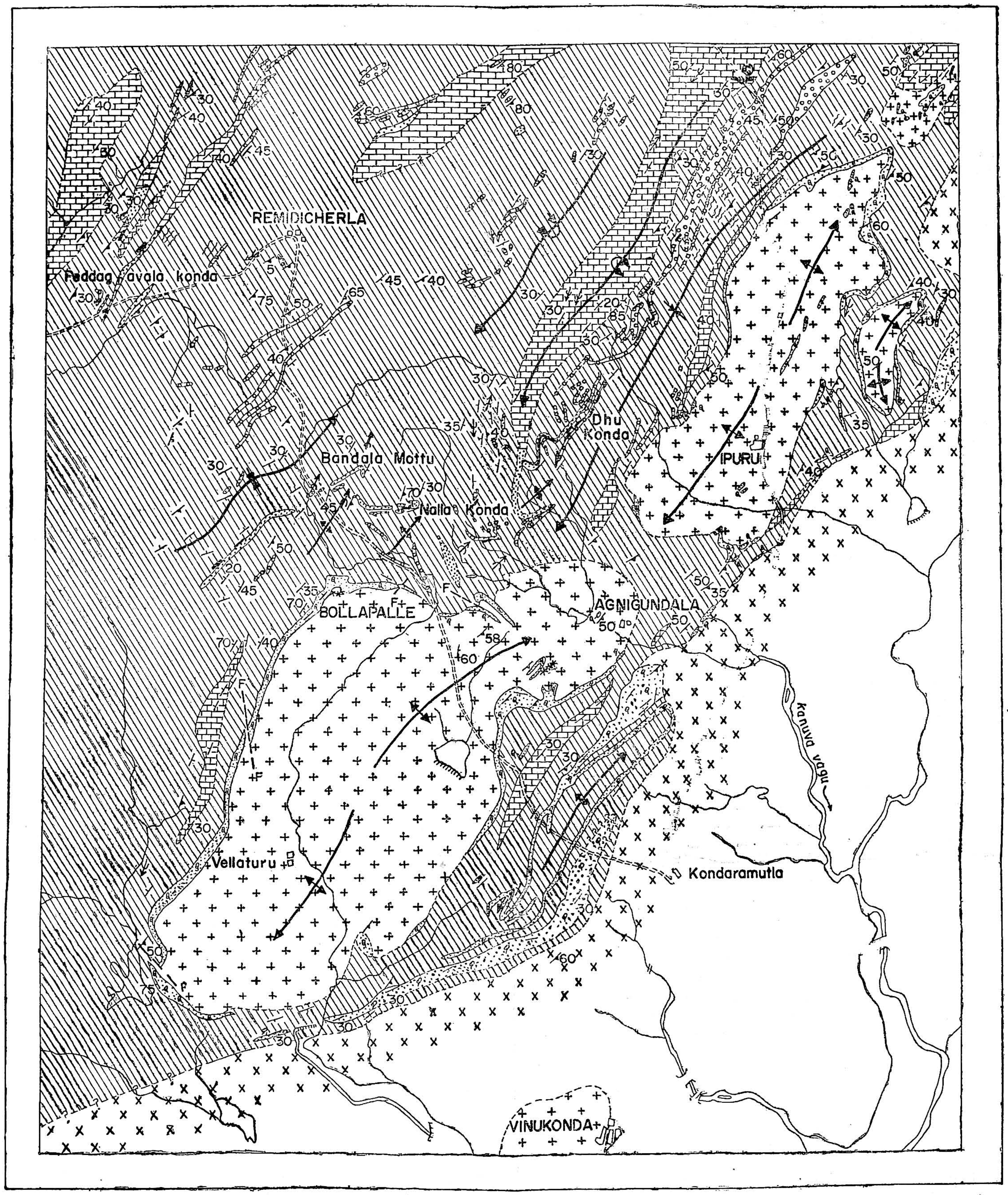
PLATE 1

GEOLOGICAL MAP OF THE AGNIGUNDALA MINERALISED BELT, ANDHRA PRADESH

SCALE

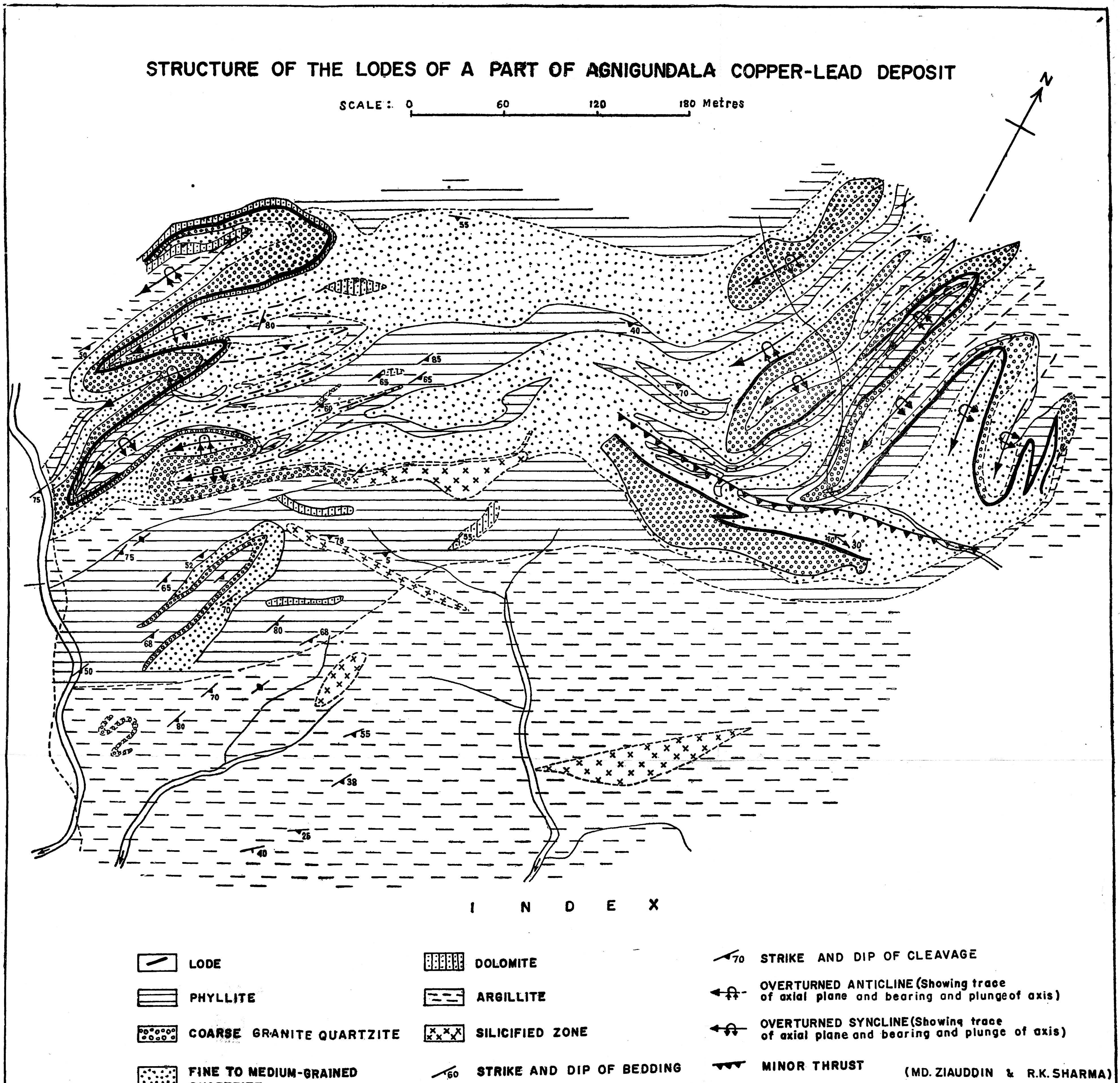
Km. 1 1/2 0 1 2 3 Km.



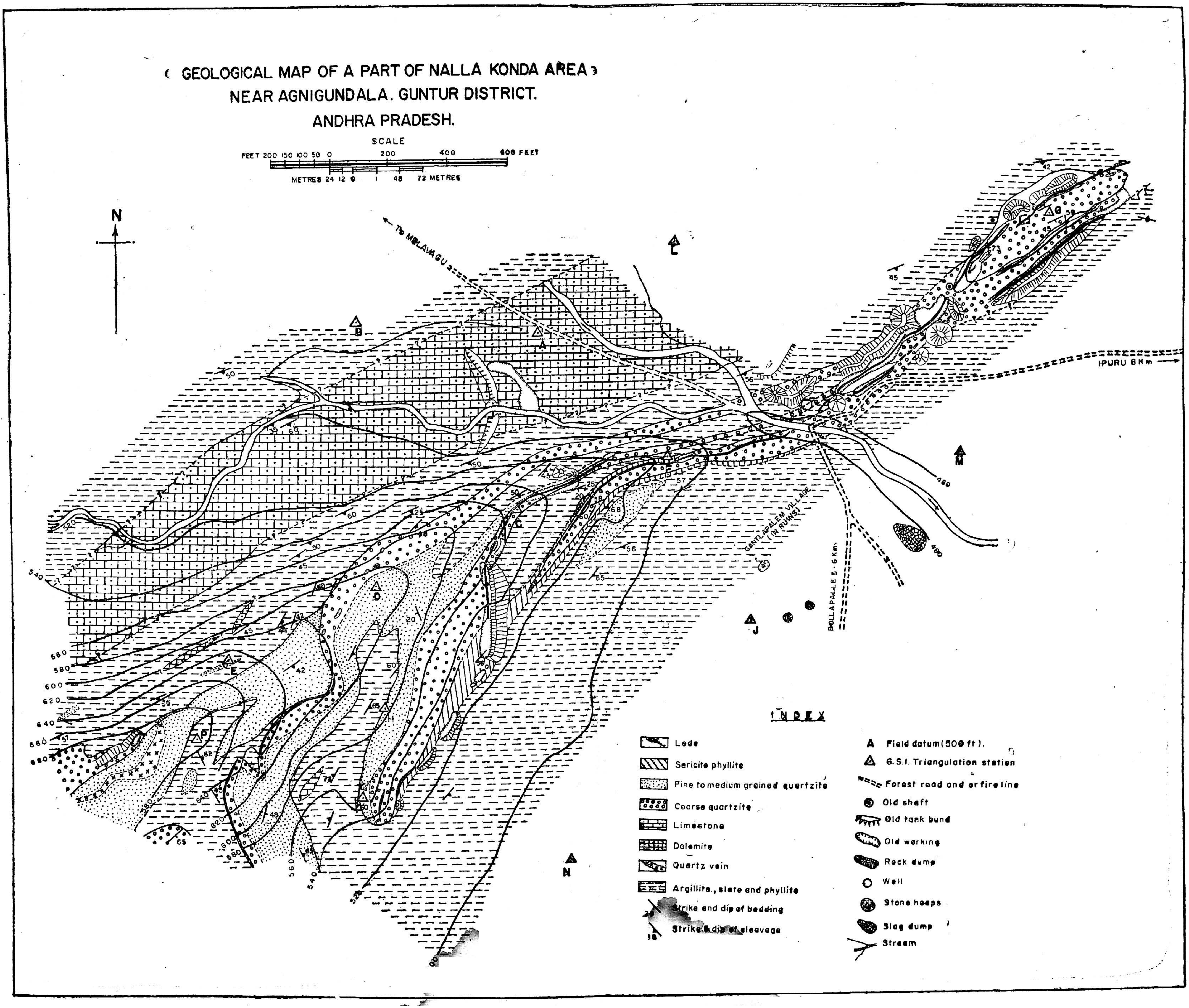
INDEX

- Mineralised zone
- Upper quartzites
- Dolomite, Calcareous argillite & Limestone
- Argillite-slate, Chlorite-phyllite and Sericite-phyllite
- Lower quartzites ?(By Renconda)
- Coarse granite with dolerite dyke
- Biotite gneisses, Quartz. sericite schist, amphibolite etc
- Dip and strike of bedding
- Dip and strike of foliation
- Plunge of minor anticline
- Plunge of minor syncline
- Axis of major anticline and plunge
- Axis of major syncline and plunge
- Axis of major overturned anticline
- Axis of major overturned syncline
- Shear fracture (Silicified)
- Fault

PLATE 2



G. S. I., Calcutta.


GEOLOGICAL MAP OF A PART OF NALLA KONDA AREA
NEAR AGNIGUNDALA. GUNTUR DISTRICT.
ANDHRA PRADESH.
SCALE
FEET 200 150 100 50 0 200 400 600 FEET
METRES 24 12 0 48 72 METRES
N
To MELAVAGU
IPURU 8 Km
GANTLAPALEM VILLAGE (IN RUINS)
BOLLAPALLE 5·6 Km
INDEX
Lode
Sericite phyllite
Fine to medium grained quartzite
Coarse quartzite
Limestone
Dolomite
Quartz vein
Argillite, slate and phyllite
Strike and dip of bedding
Strike & dip of cleavage
Field datum (500 ft).
G.S.I. Triangulation station
Forest road and or fire line
Old shaft
Old tank bund
Old working
Rock dump
Well
Stone heaps
Slag dump
Stream

GEOLOGY AND COPPER MINERALISATION IN THE GANI COPPER BELT, KURNOOL DISTRICT, ANDHRA PRADESH

BY

P. S. RAO,

Geological Survey of India.

(With Plates 3—5)

ABSTRACT

Surface indications for copper in Gani belt, Kurnool district, Andhra Pradesh, consist of a number of old workings and vein quartz zones with occasional disseminations of copper pyrites distributed at irregular intervals over a length of 16 km. They are confined to Tadpatri shales and associated trap sills of Cuddapah age, controlled in the vicinity of E.S.E. trending *en echelon* shear-faults in the drag folded, asymmetrical, easterly plunging anticlinal valley south of Gani-Kalava. Exploratory drilling has proved that geophysical anomalies are due to carbonaceous matter in shales and traps. Drilling along the old workings has, however, shown lenticular lodes of copper-ore, having thicknesses of 1 to 2.5 m.: and copper content varying from 1.31 to 2.74 per cent in both Kalava and Gani areas, but the strike and depth extensions of these lenses are rather limited, Deep drilling should be taken up to prove conclusively or disprove the economic value of the deposits.

INTRODUCTION

At Gani, copper-ore occurs in an east-west trending narrow belt situated along the northern margin of the Eramala range of hills in Nandyal and Kurnool *taluks* of Kurnool district. The main copper mineralisation is along an east-west trending valley flanked to the south by Undutla plateau and to the north by the Kalava wall, a narrow ridge made up of steeply dipping Paniam quartzite.

An attempt is being made to analyse and evaluate the results of prospecting by drilling, and to indicate the potentialities of the area.

GEOLOGY

The rock formations in the Gani copper belt belong to the power Cuddapah and Kurnool systems (Pls. 3 and 3A). The former

consists of Vempalle limestones, *Pulivendla quartzites*, Tadpatri shales and slates with intercalated thin dolomitic limestone beds and associated basic sills of dolerite and gabbro. The latter is represented by Banganapalle sandstones and conglomerates, *Jammalamadugu* limestones, Paniam quartzites and Kundair limestones and shales. The Cuddapah rocks occupy the east-west trending Gani-Kalava valley. The Kurnool formations cap the Undutla plateau in the south, and form the narrow ridge popularly known as the Kalava wall and occupy the plains to the north. The Kurnool rocks lie unconformably on the upturned and denuded edges of the Cuddapahs.

The Gani-Kalava valley represents a drag folded asymmetrical anticline with a low dipping southern limb (8 to 12° in Kurnool rocks and 15 to 30° in Cuddapah rocks) and a steep dipping northern limb (30° from vertical). The anticline plunges at low angles in a N. 80° E. direction. The amount of the plunge varies from 8° to 12° in Kurnool formations and from 20° to 30° in the Cuddapah formations. This non-conformity in the amount of the plunge and dips between the Cuddapah and the Kurnool formations, indicates that the Cuddapahs were originally tilted to the east and possibly slightly folded after the emplacement of the basic sills, before the deposition of the Kurnools. There are, however, no unequivocal evidences in the present area to prove or disprove a definite pre-Kurnool folding.

The anticline was refolded into a number of dextral and sinistral drag folds. The axes of the dextral folds trend in an E.N.E.-W.S.W. direction and plunge towards E.N.E. at angles varying from 20° to 40°. The axes of the *sinistral* drag folds trend roughly in a W.N.W.-E.S.E. direction, and plunge at low angles towards W.N.W. on the northern limb and towards E.S.E. on the *southern* limb of the anticline.

The drag folding was accompanied by the development of a number of shear faults along the steep northern limb of the anticline. The faults after trending for some distance along the southern side of the Kalava wall, cut across the anticline in an *en echelon* pattern, roughly parallel to the axes of the sinistral drag folds. Many of these faults are normal and dip steeply towards north. In each case the north block seems to have moved relatively westwards as also downwards and the south block eastwards and upwards. Some of the faults affecting only the Tadpatri rocks seem to be reverse faults with the north block moving westwards and upwards.

COPPER DEPOSITS

Surface indications of copper mineralisation consist of (1) a number of old workings, (2) quartz vein zones carrying some disseminations of chalcopyrite, and (3) coatings of malachite and azurite on the walls of the workings and in the debris. The ancient workings are seen distributed at irregular intervals over a length of 16 km. in the Gani-Kalava valley. They are confined mostly to Tadpatri shales and associated basic sills. Only some malachite stains, pyrite and barytes are seen in a few outcrops of Jammalamadugu limestones and Kundair shales.

Chalcopyrite is the chief copper mineral, disseminations of which are seen in quartz veins at some places. Traces of this mineral are seen along the contacts of thin veinlets of quartz which ramify the shales and basic sills exposed in the old workings. Less commonly, specks of chalcopyrite are seen in dolerite, quartzite and dolomitic limestones also. No chalcopyrite is seen in the rocks exposed on the walls of the few workings situated in Vempalle limestones, but numerous patches of malachite and azurite are seen. Secondary chalcocite is seen at places surrounding small specks of chalcopyrite. Traces of covellite are also observed in some places while pyrite is a common associate. Ore microscopic study of the core samples by the Indian Bureau of Mines, revealed the presence of bravoite ; pyrrhotite, tetrahedrite and boulangerite are seen in the form of inclusions in chalcopyrite.

Quartz veins are the chief carriers of the copper minerals. They occur both as individual veins and as broad vein zones consisting of numerous small and large veins. Some of the individual veins are as much as 2·5 m. in width and are traceable for about 90 m. Most of them dip northwards or are vertical. Both the quartz veins and the associated old workings are distributed in an *en echelon* pattern in and around shale-dolerite contacts.

Many of the quartz veins enclose a number of angular fragments of the country rocks, and contain cavities filled with more or less well developed quartz crystals grown from the walls towards its centre. These features indicate that the veins are essentially fracture fillings and are of hydrothermal origin. The vein quartz is milky white in

colour and somewhat cherty in appearance resembling meso-to epithermal quartz.

Wall rock alteration accompanying the mineralisation, though not very prominent, is nevertheless quite widespread. It includes chloritisation, silicification and introduction of carbonates. Exploratory drilling has shown that the wall rock alteration is much more widespread than what is apparent from the surface exposures, and that it also includes introduction of carbonaceous and graphitic material.

GEOPHYSICAL ANOMALIES

Geophysical surveys have indicated 16 self-potential anomaly centres of high magnitude in the whole belt (Pl. 4). Magnetic survey did not reveal any significant anomalies. On the other hand resistivity traverses appear to have broadly corroborated some of the S. P. indications.

Out of the 16 self-potential anomalies, three, *viz.*, Nos. 1, 2 and 3, located in the vicinity of some black shales, were therefore attributable to carbonaceous matter.

Most of the anomaly points, however, do not coincide with the lines of old workings; but like the latter and the quartz veins, are mostly situated near shale-dolerite contacts, thereby indicating the possibility of their being caused by sulphide bodies at depth. It is also noticed that most of the anomaly points lie in the vicinity of the *en echelon* shear faults, and the axes of the anomaly zones trend roughly parallel to the trend of the faults.

STRUCTURAL CONTROLS AND AGE OF THE MINERALISATION

The concentration of the mineralisation in and around shale-dolerite contacts, may at first suggest a genetic relationship between the basic sills and the mineralisation, and a pre-Kurnool age for the phenomenon. This, however, does not appear to be the case as the quartz veins which are the main carriers of chalcopyrite do not show any signs of post-Kurnool folding or faulting.

The location of the old workings and quartz veins along the axial region of the anticline suggests that the axis has acted as a controlling factor, at least, on a regional scale.

Minor anticlinal rolls on the limbs of the anticline also appear to constitute one set of the controlling factors, as evidenced by the location of quite a few old workings and in localities where the minor folds are found in good numbers with their axes roughly parallel to the trend of the individual workings.

It is seen that the mineralisation feature are all concentrated in the vicinity of the shear zones, especially where they cut across the axial region of the anticlinal structure. The faults must, therefore, have played a dominant role in localising the mineralisation.

Old workings and quartz veins, however, do not occur uniformly all along the faults ; at intervals they are located adjacent to the faults with their trends disposed at an angle to their trend. This angle is nearly the same at which tension fractures develop along side such faults.

It may thus be summarised that the mineralisation is controlled by tension fractures developed along side the shear faults where they cut across the axial region of the anticlinal structure, the location of the tension fractures being much influenced by the shale-dolerite contacts and minor anticlinal rolls.

All these structural features which control the mineralisation, in one way or the other, are of post-Kurnool age. So it can be concluded that the copper mineralisation took place in post-Kurnool times possibly after the cessation of the folding and faulting of the area.

RESULTS OF EXPLORATORY DRILLING

Though the surface indications for copper-ore are not well marked, the existence of quite a number of old workings and their long strike extension, the high magnitude of the S. P. anomalies, and the excellent structural control for ore mineralisation warranted an exploratory drilling programme, to locate any workable ore bodies

along the axes of the anomalies and in the ground covered by the old workings.

The two most promising areas in the belt *viz.*, Kalava and Gani areas, were selected for the drilling operations, which were first commenced in the former and later shifted to Gani area. In Kalava area equal emphasis was laid on testing the causative bodies of the anomalies as well as in exploring the ground covered by the old workings. Based on the results in Kalåva area the emphasis was shifted almost entirely on testing the ground covered by the old workings in Gani area.

A total number of 15 holes, seven in Kalava area and eight in Gani area, were put down. Out of the seven holes in Kalava, four (Nos. GK-1, 3, 4 and 5) were put down in the anomaly zones, and three were put down to test the ground below the old workings. In Gani area seven holes were drilled to explore the ground below the old workings, and only one (GG-3) was put down to test an anomaly centre.

Drilling in anomaly zones

Drilling in anomaly zones has shown that the anomalies are caused not by sulphide bodies but by large quantities of graphitic and carbonaceous matter impregnating the shales and dolerite (Pl. 5). This, however, does not preclude the possibility of finding rich sulphide bodies at depth in the anomaly zones for two reasons : (1) the graphitic and carbonaceous matter, like the copper mineralisation, is hydrothermal in origin and is related to it (2) boreholes GK-2 and 6 drilled in the old workings area of Kalava, passed through a wide graphitic and carbonaceous zone before intersecting intense sulphide mineralisation, and carbonaceous shales and dolerite were intersected in borehole GG-8 in Gani area below a zone of good sulphide mineralisation.

Drilling near old workings

Kalava area (Pl. 5) : Boreholes GK-2 and 6 were drilled in the same vertical plane passing through the alignments of both the holes. Two thin mineralised quartz veins were intersected in GK-2 between depths (30.39—30.75 m. and 46.09—46.30 m.*) with copper content of

* Depths as measured along the hole

1.13 per cent and 1.80 per cent respectively. Both are intersected in shale. Borehole GK-6, put down to test the depth persistence of the mineralised quartz veins, also intersected two chalcopyrite rich thick quartz veins, one between 46.36—49.13 m.† and the second between 69.46—69.86 m.† The former is at shale—dolerite contact, and the latter is completely in dolerite. Their average copper contents are 2.74 per cent and 2.04 per cent respectively. A correlation of the borehole data gives the quartz veins a dip of 65° to 70° towards north. On that basis the proved depth persistence of lodes will be over 21 m.

In order to explore the strike and further depth extension of the mineralised quartz veins, another hole, GK-7 was put down. This hole was drilled in such a way that it would meet the anticipated mineralised zone east of borehole Nos. 2 and 6 at a distance of 158.5 m. along the strike, and at a depth of 121.92 m. down dip from the surface. Neither the anticipated mineralisation nor any new zone of significance was intersected. The failure of this hole may be taken as indicative of the fact that the mineralised tension fractures do not extend that far from the shear fault and the axis of the regional anticline which form the two important controlling factors of mineralisation.

The possibility of the mineralised quartz veins extending westward (along the strike) up to the nearest shear fault and at least half the distance towards borehole GK-7, and their further depth continuation have to be proved. Further the mineralisation intersected in these holes is on the northern limb of the anticline near its axis. As such there are chances of finding similar mineralisation, also on the southern limb of the fold.

Gani area : Boreholes GG-1, 2 and 4 were drilled to test the ground covered by various groups of old workings. Borehole GG—1 intersected a mineralised quartz vein with an average copper content of 1.31 per cent between 88.64—91.29 m. Borehole GG-2 also intersected a thick but mostly barren quartz vein between 76.50—79.25 m. and a barren quartz vein between 106.67—107.89m. Borehole GG-4 intersected neither any mineralisation nor any barren veins of significance. In this connection it is significant to note that the group of old workings near the hole, appear to be situated along the axis

† Analytical data of core samples supplied by the Indian Bureau of Mines.

of minor anticlinal rolls. These minor folds plunge at low angles in a westward direction. If these minor folds control the tension fractures and the associated mineralisation, then the pitch of the ore bodies is likely to be towards west. If so, the borehole would have missed them as its direction is nearly parallel to that of the plunge,

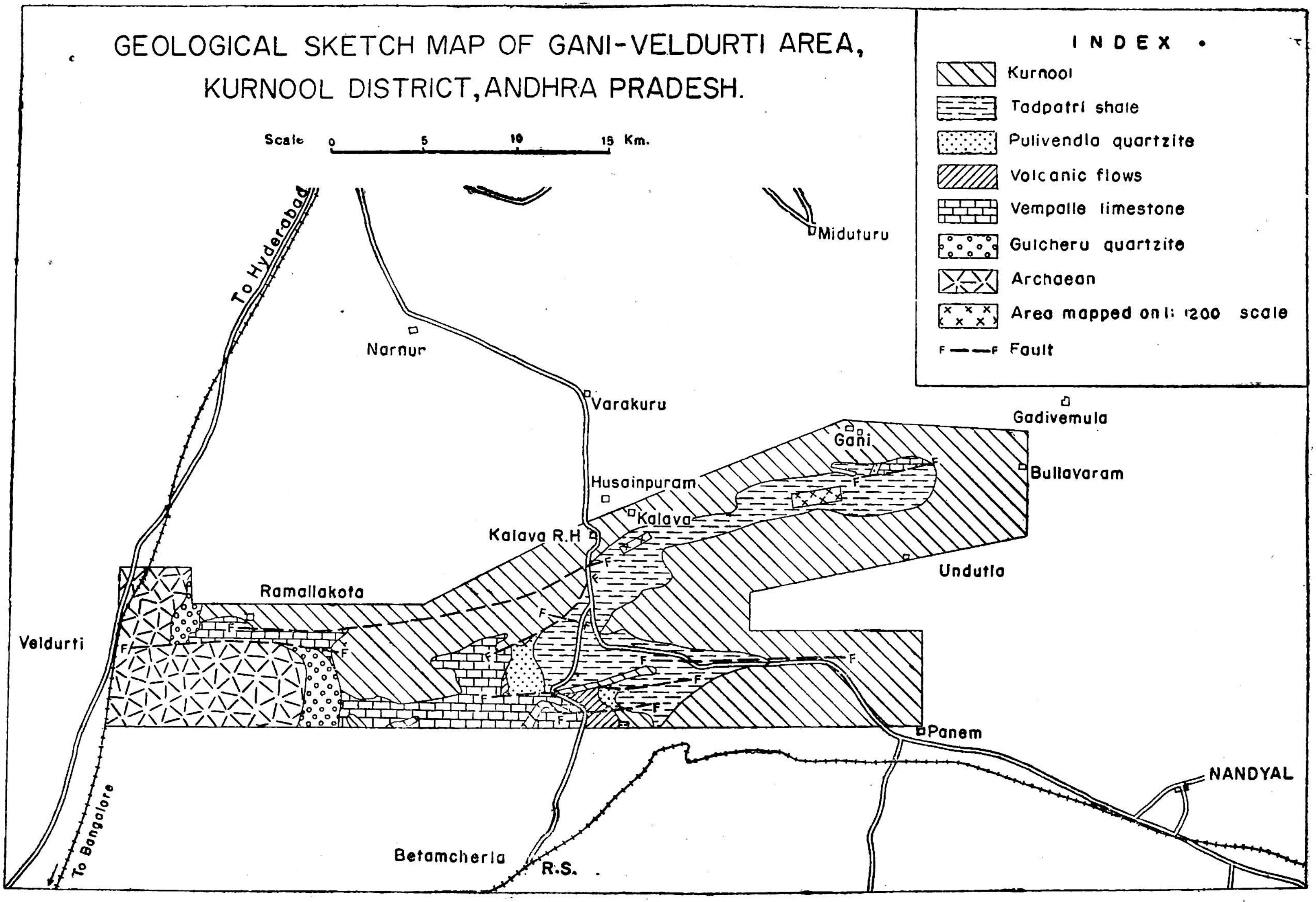
Borehole Nos. GG-5, 6 and 7 were drilled to explore the strike extension of the mineralised quartz vein met with in GG-1, and borehole GG-8 was drilled to test its depth persistence. Mineralisation of interest was intersected only in GG-5 between 65.04-65.68 m. It is associated with a vein quartz and has an average copper content of 1.57 per cent. In the other three boreholes a nnmber of quartz veins and vein quartz were intersected but no useful mineralisation could be recorded. The borehole data indicates that the mineralised quartz veins and the other quartz veins have more or less vertical dip. Further it is seen that sulphide mineralisation is not uniform even over 120 m. (400 ft.) strike length, and over 60 m. (200 ft.) down dip. In other words it suggests that the intense sulphide mineralisation occurs in the form of small lenses.

The drilling data have proved that rich sulphide mineralisation is associated only with thick quartz veins and quartz vein zones, but all the quartz veins need not contain rich mineralisation. Minor disseminations and a few big grains may be seen without any visible relation to vein quartz.

In borehole Nos. GK-6 and GG-1, 5, 6, 7 and 8 thick quartz veins and quartz vein zones, some of them carrying rich sulphide mineralisation, were intersected right within dolerite (Pl. 5). This clearly indicates that the localisation of quartz veins and the associated mineralisation are controlled more by through going fractures than by the shale-dolerite contacts.

The mineralised quartz veins met with in borehole Nos. GK-2 and 6 in the Kalava area, and those found in borehole Nos. GG-1 and 5 in the Gani area, do not appear to correspond to the old workings on the surface, nor are there any other features on the surface to indicate their presence at depth. They seem to be blind lodes as is the case with the carbonaceous matter in the anomaly zones. This feature is of special significance in view of the fact that surface indications for copper are rather poor in the entire area.

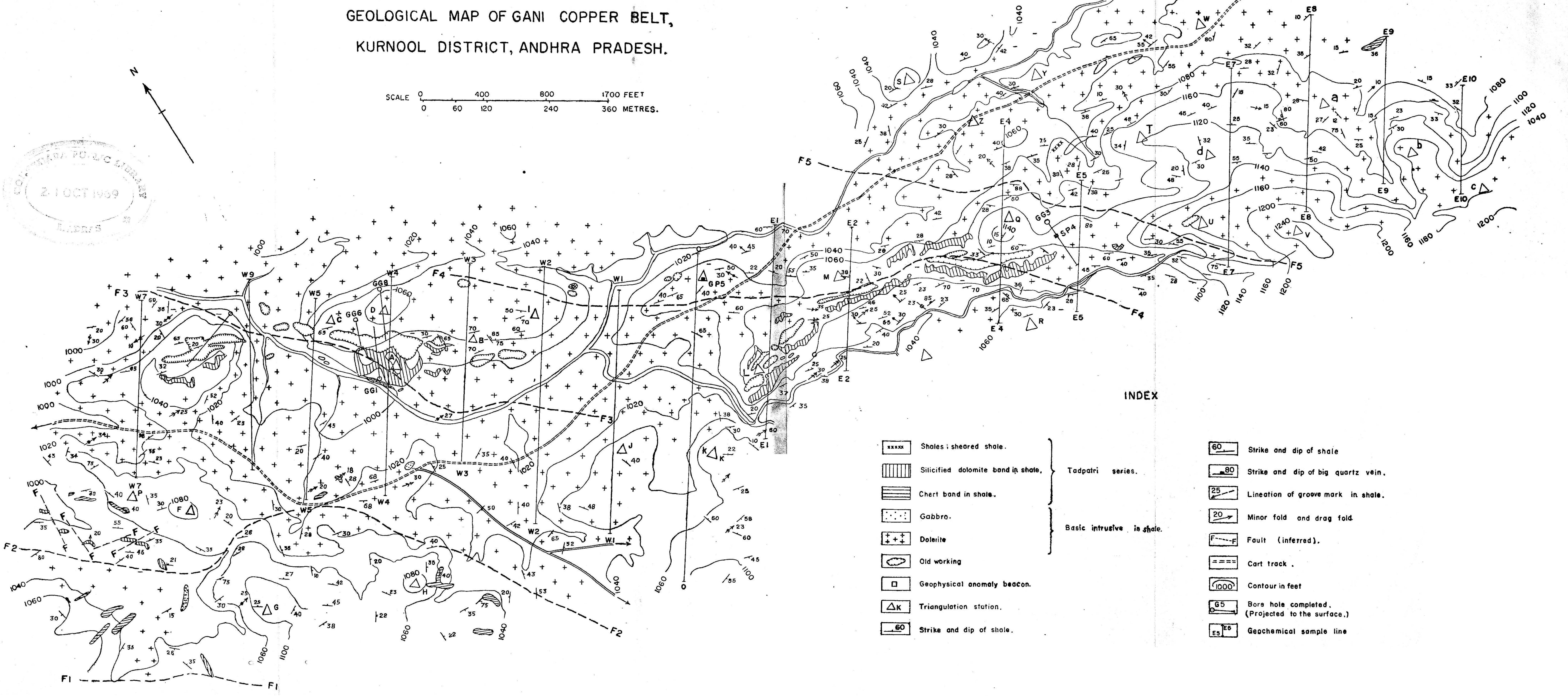
PLATE 3


GEOLOGICAL SKETCH MAP OF GANI-VELDURTI AREA, KURNOOL DISTRICT, ANDHRA PRADESH.
Scale 0 5 10 15 Km.
INDEX
Kurnool
Tadpatri shale
Pulivendla quartzite
Volcanic flows
Vempalle limestone
Gulcheru quartzite
Archaean
Area mapped on 1: 1200 scale
Fault
To Hyderabad
Miduturu
Narnur
Varakuru
Gadivemula
Gani
Bullavaram
Husainpuram
Kalava
Kalava R.H
Undutla
Ramallakota
Veldurti
Panem
NANDYAL
To Bangalore
Betamcherla
R.S.

GEOLOGICAL SURVEY OF INDIA

GEOLOGICAL MAP OF GANI COPPER BELT, KURNOOL DISTRICT, ANDHRA PRADESH.

2-1 OCT 1969



GEOLOGICAL MAP OF THE GEOPHYSICAL ANOMALY ZONE IN KALAVA AREA, GANI COPPER BELT, KURNOOL DISTRICT, ANDHRA PRADESH

21 OCT 1969

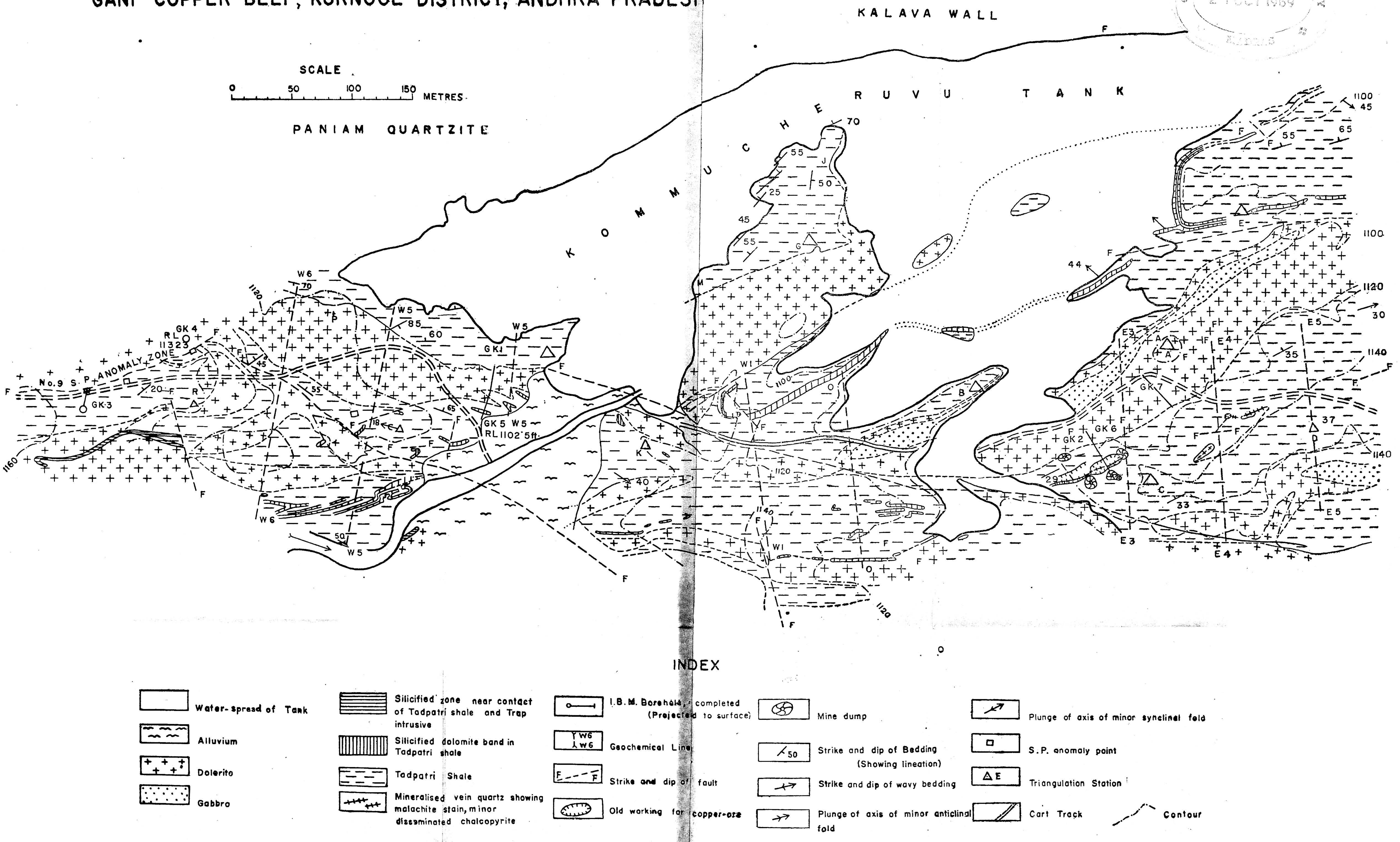


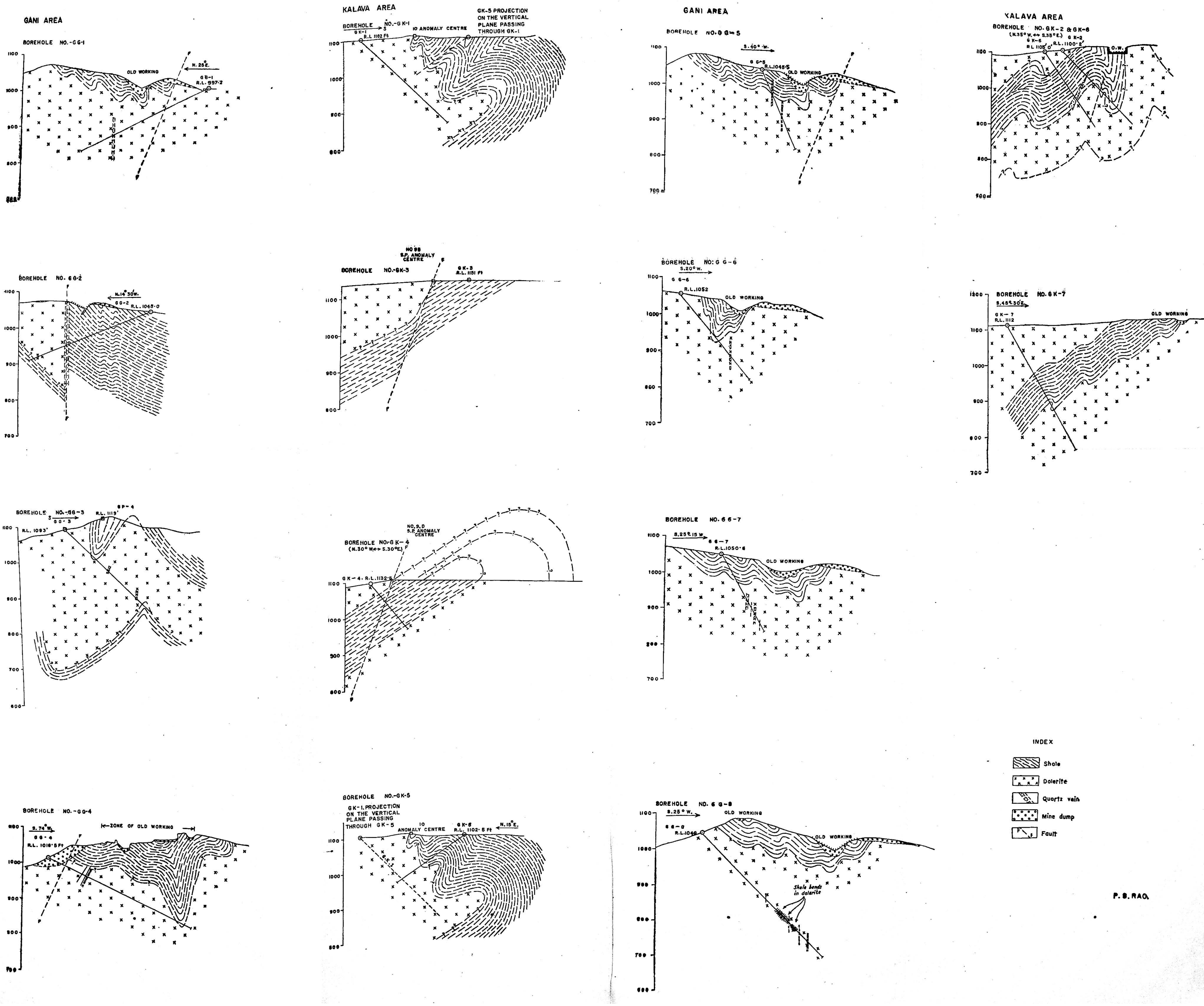
PLATE 5

VERTICAL SECTIONS ALONG BOREHOLE ALIGNMENTS IN THE GANI COPPER BELT, KURNOOL DISTRICT, ANDHRA PRADESH

SCALE

FEET 100 50 0 100 200 300 FEET

VERTICAL = HORIZONTAL



P. S. RAO.

CONCLUSION

The mineralisation in the Kalava-Gani belt has been mainly controlled by tension fractures developed alongside the *en echelon* shear faults where they cut across the axial region of the regional anticline, the location of the fractures being much influenced by shale-dolerite contacts and minor anticlinal rolls. The drilling data have shown that the mineralisation is controlled more by through going fractures than by any stratigraphic contacts, although surface indications for copper are mostly confined to such contacts.

Exploratory drilling has proved that the geophysical anomalies are not due to any large sulphide bodies but due to carbonaceous and graphitic matter. This, however, does not mean that no rich sulphide lodes exist in the anomaly zones.

Rich copper mineralisation appears to be restricted, at least within the depths explored, only to thick quartz veins and quartz vein zones, but all quartz veins do not carry rich mineralisation. Further the intense sulphide mineralisation seems to occur in the form of small lenses. Such small lenses are difficult to be intersected and proved by a few drillholes.

On the whole the chances of finding large reserves of copper within shallow depths seem to be meagre. The through going nature of the fractures and the associated quartz veins, as well as the existence of more favourable rock formations like Pulivendla quartzites and Vempalle limestones at depth below the shales indicate the possibility of finding richer ore bodies at depth. Taking all factors into consideration, a further thorough exploration of the belt by drilling especially to greater depths, needs to be taken up.

GARIMANIPENTA COPPER BELT, NELLORE DISTRICT, ANDHRA PRADESH

By

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Geological Survey of India.

(With Plate 6)

ABSTRACT

The main copper-ore occurrences of Garimanipenta area in Nellore district, Andhra Pradesh, are confined to the group of old workings around Garimanipenta, east of Somalaregada, and other places, localised in Archaean gneisses and Dharwar schists. The surface indications are of the nature of sporadic and scattered occurrences of lenticular, impersistent stringers and veins of copper-ore, associated with vein quartz and pegmatite traversing amphibolites, mica-schists and quartzites.

The shallow old workings and other features noted do not appear to indicate that the deposits are of much value. However, a few more drillholes have been suggested in order to test the ultimate possibility.

INTRODUCTION

The Garimanipenta copper belt is located along the Pillaperu river in the north, about 24-32 km. around Garimanipenta (14°59′ : 79°32′).

Geological formations and Structure

The area consists of (1) Archaean gneisses and schists in the eastern part belonging to Peninsular gneissic complex and (2) fairly broad belt of Dharwar schists in the western part. The gneissic group consists predominantly of garnetiferous mica-schists and gneisses, intermixed with bands of granite, and coarse pegmatite. Lenticular bands of amphibolite and hornblende-granulite, crystalline limestone, calc-gneiss and coarse-grained quartzite traverse the gneissic rocks at

some places following the direction of general foliation. The quartzite, crystalline limestone and calc-gneisses are associated with the schistose rocks of the area. The amphibolites and hornblende-granulites appear to be the metamorphosed basic intrusives into the original metasediments.

The Dharwar schistose group consists of a succession of (a) mica-schists with interbedded metasediments like quartzites and limestones in the east, followed westward by (b) metavolcanic actinolite-schists with a large group of quartzite, quartz-schists and quartz-mica schists. These later quartzites are often cross-bedded and carry zones of pebble beds. Both gneissic rocks and the Dharwar schists are traversed by vein quartz and pegmatites which locally carry mica.

The quartzites, amphibolites and other marker beds are highly contorted and disrupted and occur within the gneissic, and schistose formations, making the structure somewhat obscure. The belt of Dharwar schists and associated quartzites in the west appears to form a predominantly westerly dipping isoclinal structure. There is, however, no major structural feature in the vicinity of the old copper workings near Garimanipenta or Somalaregada and other copper workings in the area.

Copper Deposits

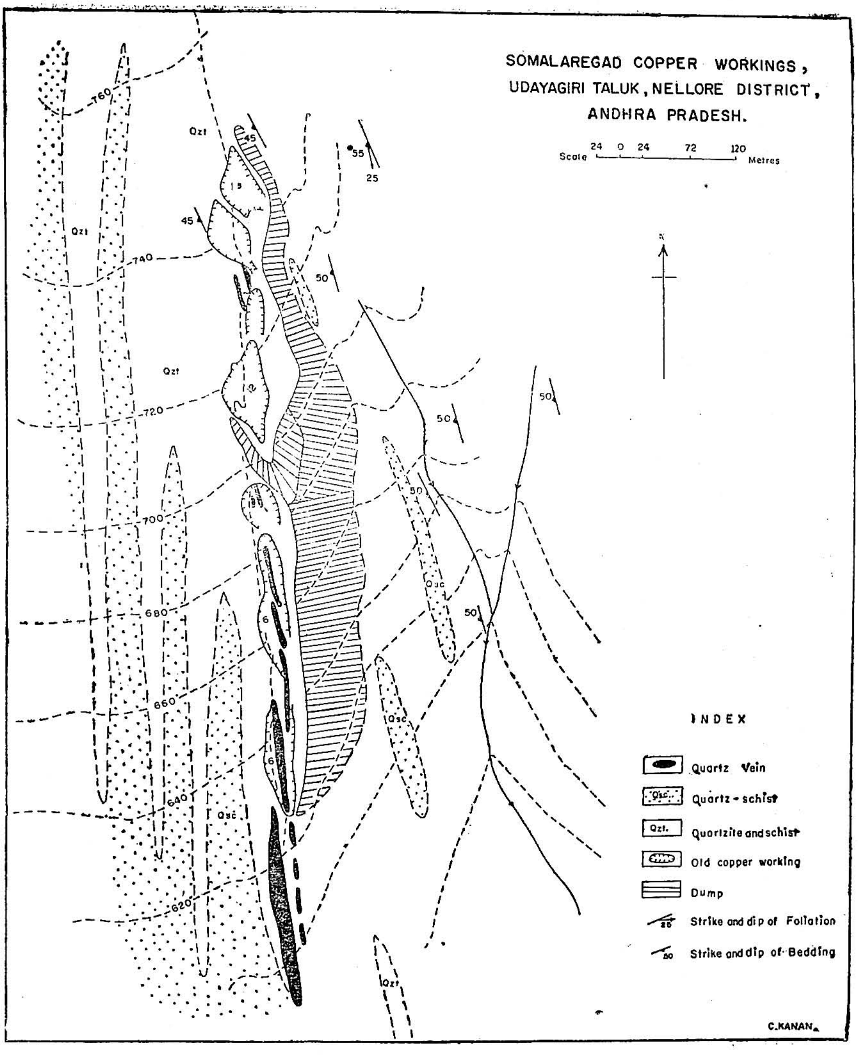
The main copper deposits of the area are confined to the old workings, south of Garimanipenta village, and a smaller prospect (E-mine) on the northern side of the Pillaperu river, four kilometres north of Garimanipenta. Another prominent group of old workings is of those found along the northern part of the Duttaluru quartzite ridge east of Somalaregada (Pl. 6). In addition, sporadic occurrences of malachite, pyrite and chalcopyrite associated with vein quartz and pegmatites in mica-schists and amphibolites are found at several places.

The investigation of the deposits indicates that the copper-ores in the area occur sporadically as lenticular masses, impersistent stringers and veins, now mostly altered to malachite and azurite. The ore is associated with vein quartz and pegmatite, containing biotite and muscovite, and at places tourmaline. The old workings near Garimanipenta indicate no definite zone of mineralisation and represent unsuccessful prospecting pits and trenches. The old workings on the

ridge, 1.5 km. east of Somalaregada, reveals only sparse malachite stains in vein quartz and quartzites. The mineralisation is more persistent along the strike and shear zone in the quartzite contact.

The surface geology and the study of old pits do not indicate any large copper lodes in this area at depth. The association of oxidised copper minerals in pegmatite is an unfavourable indication as the pegmatite is generally the root zone of metalliferous hydrothermal veins. However, about half a dozen shallow exploratory drillholes, each to a depth of about 30 to 50 m. will be necessary to study the exact nature of the strata and lodes below the existing old workings and to conclude finally the prospects of the deposits.

PLATE 6


SOMALAREGAD COPPER WORKINGS,
UDAYAGIRI TALUK, NELLORE DISTRICT,
ANDHRA PRADESH.
Scale 24 0 24 72 120 Metres
Qzt
Qsc
760
740
720
700
680
660
640
620
INDEX
Quartz Vein
Quartz-schist
Quartzite and schist
Old copper working
Dump
Strike and dip of Foliation
Strike and dip of Bedding
C.KANAN

THE OCCURRENCES OF COPPER MINERALS IN RAPUR TALUK, NELLORE DISTRICT, ANDHRA PRADESH

By

T. M. Rao,

Geological Survey of India,

(With Plate 7)

ABSTRACT

Copper mineralisation has been observed at a number of places in Rapur *taluk*, Nellore district. They include Sanayapalem, Tokanchi, Dachuru and Tirumalapadu. The mineralised zone trends roughly in a N.W.—S.E. to N.N.W.—S.S.E. direction.

The rocks in the area have suffered shearing and fracturing. The copper minerals identified include chalcocite, chalcopyrite, bornite and malachite. Besides these, zinc and lead minerals, like sphalerite and galena are also noted. Calcite, epidote and specularite are the chief gangue minerals. The copper-ores analyse 0.03 to 1.74 per cent copper.

INTRODUCTION

During 1960-61, several oocurrences of copper-ores were observed in Rapur *taluk* in Nellore district of Andhra Pradesh. These deposits were reported for the first time by the author.

The main localities of copper ocourrences are included in sheet 57 N/11 ; these are given below :—

1. Northern portions of the hillock .687 (Guttikonda), about one kilometre south-east of Sanayapalem (14°19′ : 79°88′).

2. Hillock .327, about 500 km. S.S.W. of Tokanchi (14°22′ : 79°34′).

3. S.S.E. of Dachuru (14°23′ : 79°34′), between Dachuru and Forest Rest House.

4. Southern lower levels of the hillock ·494 north-west of Dachuru, and
5. About 1.5 km. south of Tirumalapadu (14°25′ : 79°31′).

Thc area can easily be approached by road from both Gudur (*via* Rapur) or Nellore (*via* Podalakur) railway stations. The distances from these two railway stations are about 50 and 80 km. respectively.

GEOLOGY

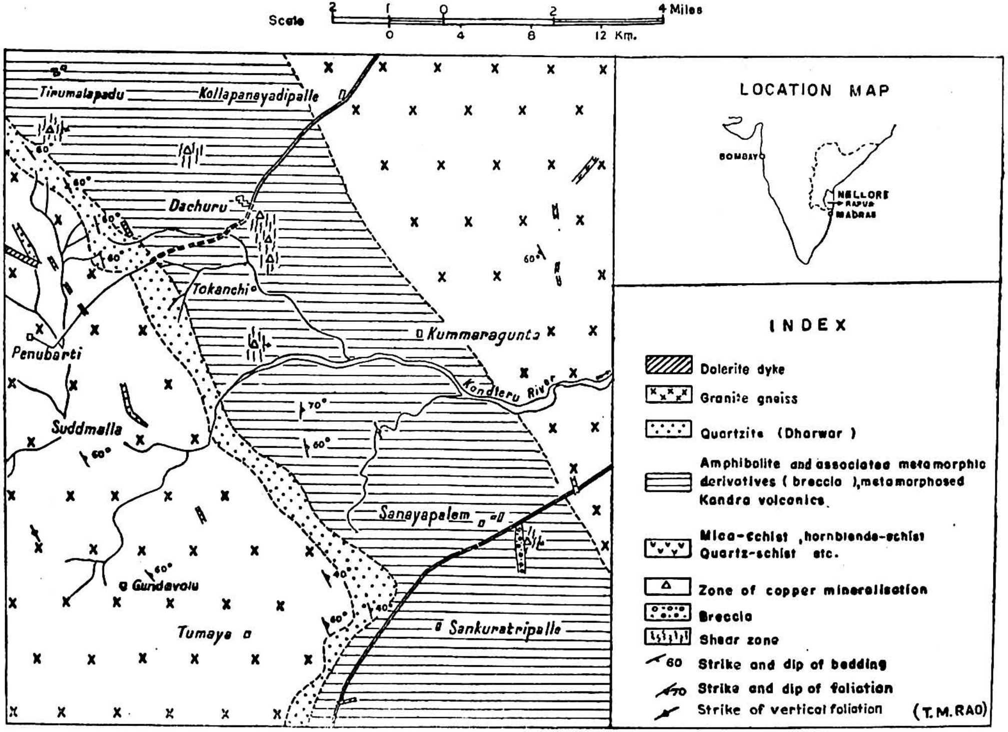
The main rock formations met with in the area are amphibolites hornblende-schists, hornblende-granite gneiss and quartzites (mostly sheared and recrystallised) all belonging to the Dharwar system. The strike of foliation of the schistose rock is between north-south and N.W.—S.E. with dips varying from 40° towards east to almost vertical. The rocks in the area are considerably sheared and fractured.

MINERALISATION

The copper mineralisation is noted mainly in the north-south to N.N.W.—S.S.E. trending shear zones in amphibolites and hornblende-schists, near the junction of the granite gneiss with either the amphibolites or hornblende-schists (Pl. 7). These shear zones are marked by crushed veins of quartz and bands of pistacite-quartzite. The mineralisation appears to be promising at locality Nos. 1, 3 and 4 and is along the shear planes trending roughly in a N.W.—S.E. to N.N.W.—S.S.E. direction. Further work is suggested to ascertain whether the mineralisation in the three localities forms parts of one continuous mineralised zone or represents detached occurrences.

The copper minerals identified include chalcocite, chalcopyrite, bornite and malachite. Sphalerite and galena are also noted associated with them. Calcite, epidote and specularite are the chief gangue minerals. Certain zeolites are also present in druses and cavities of the sheared rocks.

MAP SHOWING COPPER MINERALISATION IN RAPUR TALUK, NELLORE DISTRICT, ANDHRA PRADESH.



CHEMICAL ANALYSIS

Samples collected during the present work were analysed at the Chemical Laboratory of the Geological Survey of India, Hyderabad ; the results are given below :—

Sl. No.	Locality	Cu	Pb	Zn
1.	From the brecciated bands, S.S.E. of Dachuru	1.74%	40 p.p.m.	900 p.p.m
2.	About a mile south of Tirumalapadu	0.15%	Less than 10 p.p.m.	100 p.p.m.
3.	At the hillock ·327 S.S.W. of Tokanchi	300 p.p.m.	20 p.p.m.	350 p.p.m.
4.	At the northern portions of the hillock ·687 (Guttikonda) south-east of Sarajalun	1,800 p.p.m.	-do-	50 p.p.m.

CONCLUSION

From the above it is seen that the percentage of copper varies between 0.03 and 1.74 while lead and zinc occur only in very minor quantities. Since the preliminary work has shown some encouraging indications and since the majority of the minerals identified belong to the primary sulphides, it can be expected that workable copper deposits may exist at depth.

THE OCCURRENCES OF COPPER MINERALS IN THE WARANGAL, KARIMNAGAR, NALGONDA, MEDAK AND HYDERABAD DISTRICTS, ANDHRA PRADESH

BY

CH. NARASIMHA RAO,

Geological Survey of India.

(With Plates 8—13)

ABSTRACT

Occurrences of copper minerals at a number of places spread over an area of about 1,500 sq. km. in the Warangal and adjacent districts of Andhra Pradesh have been found. Mineralisation is usually confined to the zones of crushing and shearing, mainly in quartz veins and porphyritic granite and also at places, in pegmatites, dolerites and metagabbros. The primary copper minerals recorded are chalcopyrite, bornite, chalcocite, their alteration products, being covellite, malachite and azurite. Besides these, some lead-bearing minerals like galena and cerussite and other minerals like wulfenite, molybdenite and specularite have also been recorded. Some of these warrant further geological and geophysical prospecting.

INTRODUCTION

While carrying out the geological mapping in parts of Warangal district, copper mineral occurrences were recorded in certain crushed and sheared rocks. Mineralised zones were also located later in the adjacent areas in Karimnagar, Nalgonda, Medak and Hyderabad districts. The total mineralised area measures about 1,500 sq. km. and lies between Lat. 17°35′ and 18°15′ and Long. 78°55′ and 79°20′ in sheets 56 O/N.W., 56 N/S.W., 56 K/N.E. and 56 J/S.E. Copper minerals in similar rocks have also been reported from near Hyderabad, which is about 80 km. W.S.W. of the above mentioned area. This indicates that the area of mineralisation is likely to be extensive.

GEOLOGY

Porphyritic granite with associated composite gneisses is the prevalent rock of the area. Garnet-epidote rock, hornblende-schist, amphibolite, hornblende-biotite granulite, talcose rocks peridotite, pyroxenite, pyroxene-granulite, metagabbros, calc-silicate rocks, anthophyllite-schist, banded magnetite-quartzite, mica-schist and mica-gneiss occur as inclusions in the porphyritic granite. The porphyritic granite is intruded by dykes of aplite, pegmatite, and dolerite, and quartz veins.

The rocks have suffered crushing and shearing locally at several places. The mineralisation is confined to the quartz veins and less commonly to porphyritic granite along the crushed and shear planes especially those trending in N.W.—S.E., N.N.W.—S.S.E. or W.N.W.—E.S.E. directions. Copper minerals are also found in the crushed pegmatites, dolerites and metagabbros.

The copper minerals are chalcopyrite, bornite, and chalcocite. They alter to covellite, malachite and azurite. Associated with copper minerals, at places, are galena, cerussite, wulfenite and molybdenite. Micaceous hematite occurs as impregnations in the crushed rocks. In addition, epidote, chert, chalcedony, calcite, fluorite and quartz also occur in these zones. The cavities in the crushed quartz veins are lined with crystals of amethyst, rock crystal and reddish or greenish quartz. In places, amethyst is brecciated also, indicating later movements in these zones. The wall rocks are kaolinised.

DESCRIPTION OF MINERALISED ZONES

The copper minerals occur sporadically as grains in the mineralised zones at many localities some of which are described below:—

1. *About 1·8 km. south-west of Maikal-ghattu (17°50′ : 79°12′ ; 56 O/N.W.)* are exposures of brecciated quartz vein (0.6 to 1.8 m. wide) running for about 1.6 km. in a N.W.—S.E. direction and showing specks of galena and malachite at places.

2. *About one kilometre S.S.E. of Guntur (17°52′ : 79°10′ ; 56 O/N.W.)*, an exposure of brecciated quartz vein 0.9 m. in width runs in an east by south direction discontinuously for about 600 m. and shows traces of chalcopyrite.

3. *About 3·2 km. E.S.E. of Machapahad (17°52′ : 79°13′ ; 56 O/N.W.)*, a thin vein of brecciated quartz trends W.N.W.—E.S.E. and bears specks of galena and malachite.

4. *About two kilometres S.S.E. of .1932 (17°52′ : 79°14′ ; 56 O/N.W.)*, a small quartz vein trending W.N.W.—E.S.E. contain specks of chalcopyrite and malachite.

5. *About two kilometres north of Taragupal (17°57′ : 79°11′ ; 56 O/N.W.)*, there are stray pieces of crushed granite with small impregnations of malachite.

6. *About 2.8 km. north-east of Machapahad (17°52′ : 79°13′; 56 O/N.W.)*, there is a thin quartz vein trending N.W.—S.E. and containing traces of malachite.

7. *About two kilometres east of Gandipalli (19°91′ : 79°19′ ; 56 N/S.W.)*, there is a quartz vein which runs discontinuously for about 1.2 km. in a N.W.—S.E. direction, and contains specks of malachite and galena.

8. *About 800 m. south of Gandipalli*, there is an exposure of a small quartz vein with specks of malachite.

9. *About 1.6 km. east of .1435 (18°03′ : 79°13′ ; 56 N/S.W.)*, there are stray pieces of pegmatite with disseminated specks of malachite.

10. *About 1.2 km. east of .1435 (18°03′ : 79°13′ ; 56 N/S.W.)*, there is an isolated block of porphyritic granite with chalcopyrite, malachite, azurite, and epidote along a fracture plane.

11. *About two kilometres west of Muddulagudam (17°58′ : 79°17′ ; 56 O/N.W.)*, outcrops of quartz veins trending N.W.—S.E. and bearing specks of malachite were met with along the Kundapur-Lingampalli cart track.

12. *About 400* m. *south-west of Chipatpalli (17°58′ : 79°13′ ; 56 O/N. W.)*, there is an exposure of a small quartz vein with specks of chalcopyrite.

13. *Along the eastern flank of the hill .1649 (17°55′ : 79°16′ ; 56 O/N.W.)*, there runs a quartz vein trending N.N.W.—S.S.E. with specks of malachite.

14. *About 1.4 km. south of the hill .1654 (17°55' : 79°17' ; 56 O/N.W.)*, there is a quartz vein 0.45-1.5 m. wide, with specks of chalcopyrite, malachite, covellite and micaceous hematite.

15. *About 600 m. south-west of the hill .1640 (17°48' : 79°05' ; 56 O/N.W.)*, there is an exposure of crushed quartz vein 1.2 m. wide trending in a N. 60° W.—S. 60° E. direction, for about 800 m. Speoks of malachite occur sporadically in this vein.

16. Malachite occurs sparingly as an encrustation in the porphyritic granite exposed on the *south-eastern flank of the hill .1508 (18°01' : 79°05' ; 56 N/S.W.)*

17. *Abaut* 800 m. *north-west of Lingapur (17°59' : 79° 04' ; 56 O/N.W.)*, malachite occurs sparingly in association with pyrite and calcite in N. W.—S. E., trending fractures in the porphyritic granite.

18. *About 1.4 km. south of the hill .1420 (18°05' : 79°07' ; 56 N/S.W.)*, there are thin quartz veins traversing crushed granite, with malachite stains.

19. *About 2.6 km. west of Sandral (18°07' : 79°07' ; 56 N/S.W.)*. there are veins of crushed quartz, a few centimetres to two metres wide, with a trend of N. N. W.—S. S. E. or N.W.—S.E. They contain micaceous hematite and traces of the malachite.

20. *West of the hill .1461 (18°07' : 79°07' ; 56 N/S.W.)*, about 1·6 km. from its base, the porphyritic granite contains chalcopyrite, bornite and malachite along the fractures trending N.W.—S.E.

21. *About 200 m. east of occurrence No. 2* , there is an exposure of narrow zoned pegmatite trending N. W.—S. E. Molybdenite occurs sporadically in this pegmatite together with pyrite, chalcopyrite, malachite and calcite. *Minerals of copper occur* as specks in the N. W.—S. E. trending pegmatites exposed in the surrounding area.

22. *About 2.4 km. west of Medpalli (18°10' : 78°58' ; 56 J/S.E.)*, chalcopyrite, malachite, molybdenite and pyrite occur sporadically in a narrow, zoned pegmatite which traverses porphyritic granite.

23. Chalcopyrite and bornite occur along the N.W.—S.E. trending fractures in the porphyritic granite exposed *about 700 m. E.N.E. of the hill .1474 (18°10′ : 79°02′ ; 56 N/S.W.)*. The associated minerals are specularite, epidote, fluorite and calcite.

24. *About 1.2 km. W.N.W. of Chauraram (18°04′ : 78°56′ ; 56 J/S.E.)*, there are exposures of crushed porphyritic granite with stringers of quartz in which chalcocite and malachite are present in small quantity. In the surrounding area, brecciated quartz veins with sporadic specks of chalcopyrite, galena and malachite occur. Quartz veins, (trending W.S.W.—E.N.E.) traversing the metagabbros, contain pale amethyst and specks of chalcocite and malachite.

25. *About one kilometre west of Chauraram (18°11′ : 78°56′ ; 56 J/S.E.)* occurs a brecciated quartz vein consisting of quartz and chert. Micaceous hematite and specks of malachite and galena occur in it, at places. The vein dips vertically or steeply towards south-west. It extends discontinuously in a N. 30° W.—S.30°E. direction for about 3.5 km.

26. Specks of bornite occur along the fractures in the porhyritic granite exposed in the hillock, *200 m. north-east of Ibrahimnagar (18°09′ : 78°57′ ; 56 J/S.E.)*.

27. *About 800 m. S.S.E. of the village Silarguda (17°30′ : 78°27′ ; 56 K/7)*, there is an exposure of N.W —S.E. trending brecciated quartz vein, 0.3 to 0.9 m. wide dipping steeply towards south-west. It contains specks of chalcopyrite and galena with occasional covellite and malachite. The vein could be traced for a distance of about 100 m.

DETAILED INVESTIGATION

Six of the mineralised quartz veins were selected and investigated in detail. Large scale (1 : 3,960) maps of each of these were prepared and trenches were dug across them at intervals to depths varying from 0.3 to 0.9 m. A few samples from the mineralised veins were analysed. These veins are described below :—

(1) The mineralised quartz vein, about 3.2 km. S.S.W. of the village Katkur (18°03′ : 79°14′ ; 56 N/S.W.) runs discontinuously for

about 1.6 km. in a N.W.—S.E. direction (Pl. 8). Its width is variable, the maximum being 2.4 m. near its north-western extremity. It shows galena, chalcopyrite and malachite sporadically. Six trenches were dug across this vein. A sample collected from trench No. 1, analysed 500 p.p.m. copper and 2,300 p.p.m. zinc. The distribution of the sulphides in the vein has been found to be highly erratic.

(2) The quartz vein exposed *one kilometre S.S.E. of Khannaram,* (*18°00′ : 79°15′ ; 56 O/N.W.*) trending W.N.W.—E.S.E., runs discontinuously for about 475 m. (Pl. 9). It is up to 3.15 m. in width Chalcopyrite, covellite, malachite, azurite, galena, micaceous hematite and calcite are present at places in this vein.

(3) Quartz vein, 1.8 m. wide, bearing specks of chalcopyrite, covellite, malachite and galena is exposed about *1.8 km. N.10°E.* of *Ankshapur* (*17°58′ : 79°10′ ; 56 O/N.W.*). It runs discontinuously for about 320 m. in a N. 55°E—S. 55°W. direction (Pl. 10).

(4) The mineralised quartz vein exposed *400 m. west of Kundapur* (*17°58′ : 79°15′ ; 56 O/N.W.*) runs discontinuously for about one kilometre in N.40°W.—S.40°E. direction (Pl. 11). It has a maximum width of 2.1 m. and bears specks of chalcopyrite, covellite, malachite and galena. A few large crystals of galena were also found. White, prismatic crystals of cerussite and amber coloured, platy crystals of wulfenite were found at one place, projecting from a few cavities in the vein. The specific gravity of the wulfenite and cerussite crystals is 6.78 and 6.53, respectively. A sample of wulfenite on analysis gave the following :—

PbO	60.72%
MoO_3	39.32%
Total	100.04

Traces of calcium and tungsten have been detected in the sample by spectro-chemical analysis. One sample of the vein collected from the trench No. C—2, analysed 100 p.p.m. copper, 4,700 p.p.m. lead, 60 p.p.m. zinc, 30 p.p.m. molybdenum and 8 p.p.m. tungsten.

(5) The brecciated quartz vein, 0.3 to 2.1 m. wide, exposed 2.2 km. south of Abdul Nagawaram *(17°56' : 79°14' ; 56 O/N.W)* runs discontinuously for about 1,079 m. in west by north direction (Pl. 12). Specks of chalcopyrite, covellite, malachite, bornite and galena occur disseminated in it. One sample from the trench No. D—7, analysed 100 p.p.m. copper, 175 p.p.m. lead, 40 p.p.m. zinc, 30 p.p.m. molybdenum and 20 p.p.m. tungsten. And one sample from the trench No. D—2 analysed 380 p.p.m. copper, 60 p.p.m. lead, 160 p.p.m. zinc, 25 p.p.m. molybdenum and 30 p.p.m. tungsten. A sample from trench No. D—3 analysed 60 p.p.m. copper, 175 p.p.m. lead, 10 p.p.m, zinc, 35 p.p.m. molybdenum and 20 p.p.m. tungsten.

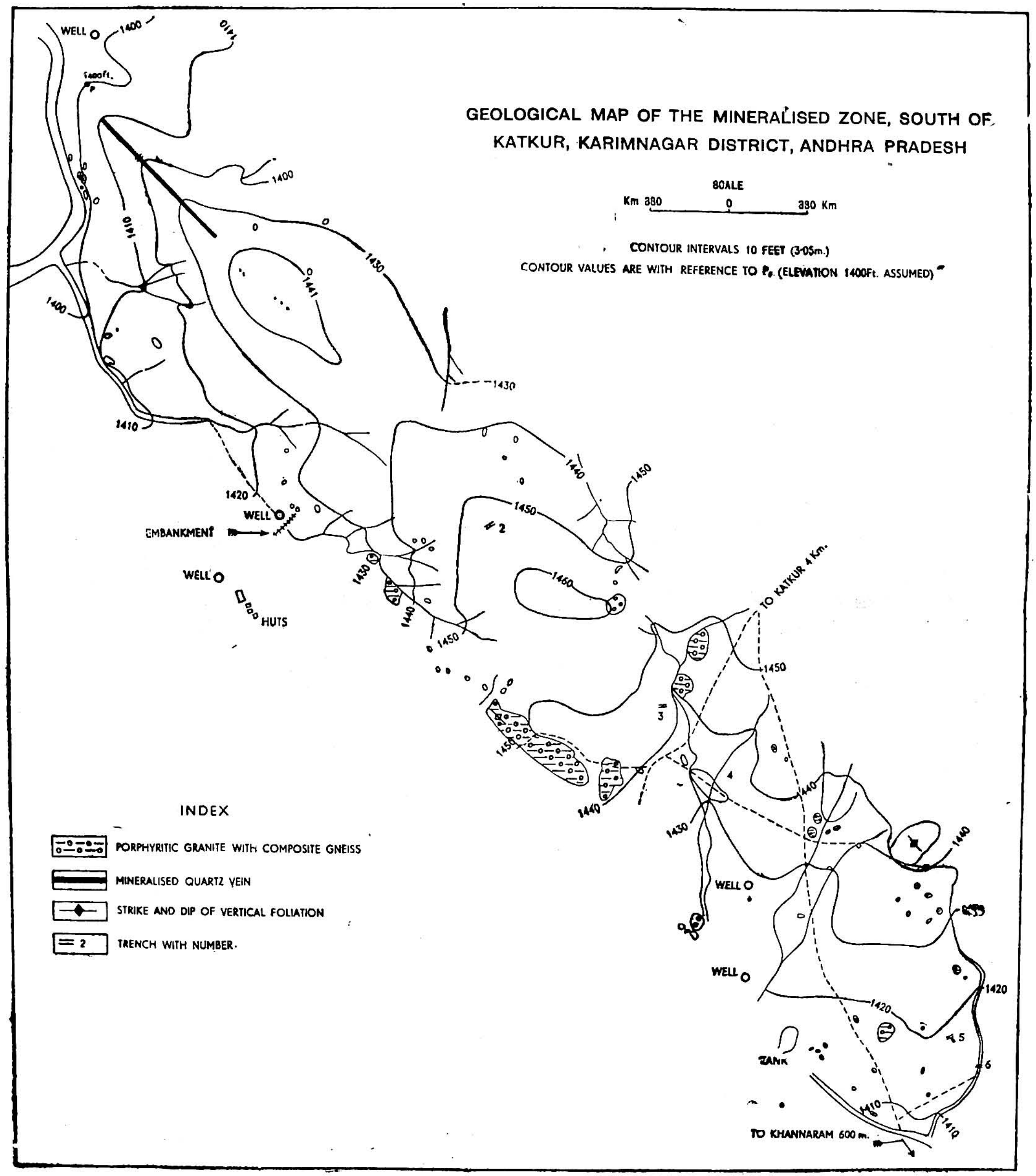
(6) The mineralised quartz vein, 15 to 75 cm. wide, exposed *two kilometres south-east of Abdul Nagawaram* (*17°56' : 79°14' ; 56 O/N.W.*) runs discontinuously for about 320 m. in a N.60°W.—S. 60°E. direction (Pl. 13). Specks of chalcopyrite occur disseminated in the vein. Chalcopyrite alters to covellite and malachite in places.

CONCLUSIONS AND RECOMMENDATIONS

The copper mineralisation in this area is confined to small crushed or shear zones. Chemical analyses show that the percentage of copper in the rocks of the mineralised zones is less than one. It is of interest to note that minerals of lead, zinc and molybdenum also occur in this mineralised areas.

Geological mapping has to be extended to the adjacent areas with a view to locating more mineralised zones. Deep trenches have to be excavated across the zones to study the distribution of copper minerals at depth. Geophysical prospecting might also be undertaken to locate concealed ore-bodies. It is suggested that, in the first instance an area of *about 20 sq. km. near Sandral* (*18°07' : 79°08' : 56 N/S.W.*) may be surveyed geophysically; as the porphyritic granite here is sheared and mineralised at places.

PLATE 8



GEOLOGICAL MAP OF THE MINERALISED ZONE, SOUTH OF KATKUR, KARIMNAGAR DISTRICT, ANDHRA PRADESH

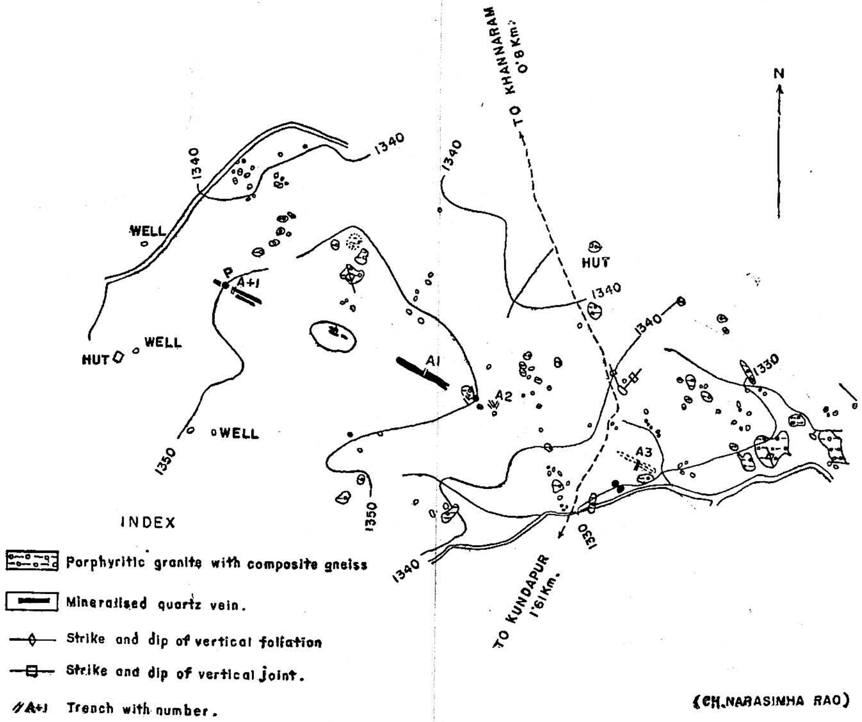
PLATE 9

GEOLOGICAL MAP OF THE MINERALISED ZONE NEAR KHANNARAM, KARIMNAGAR DISTRICT, ANDHRA PRADESH

SCALE:- 0 330 660 m

CONTOUR INTERVALS 10 FEET (3·05 m.)

CONTOUR VALUES ARE WITH REFERENCE TO P. (ELEVATION 1350 Ft. ASSUMED)

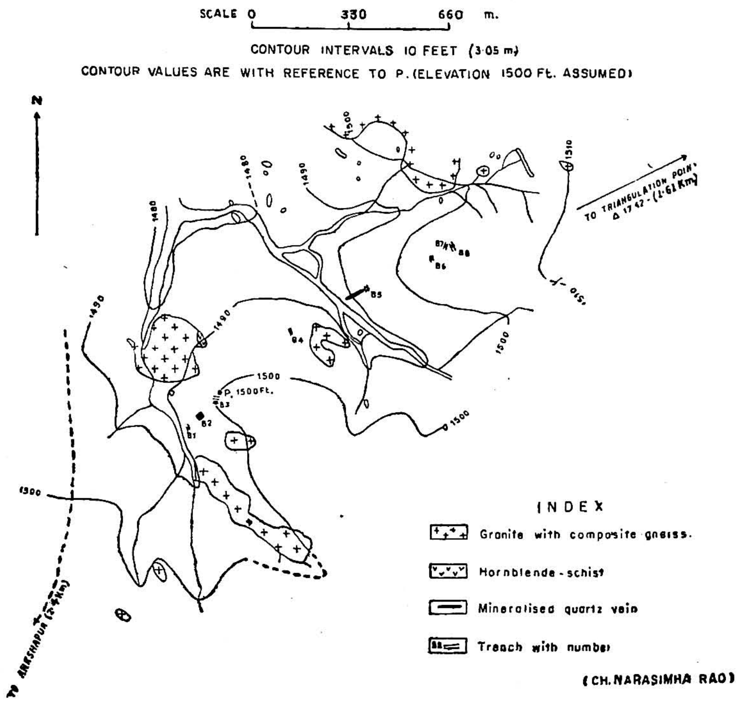


(CH. NARASIMHA RAO)

GEOLOGICAL SURVEY OF INDIA

PLATE 10

GEOLOGICAL MAP OF THE MINERALISED ZONE NORTH OF ANKSHAPUR, WARANGAL DISTRICT, ANDHRA PRADESH.



GEOLOGICAL SURVEY OF INDIA

PLATE 11

GEOLOGICAL MAP OF THE MINERALISED ZONE WEST OF KUNDAPUR, WARANGAL DISTRICT, ANDHRA PRADESH

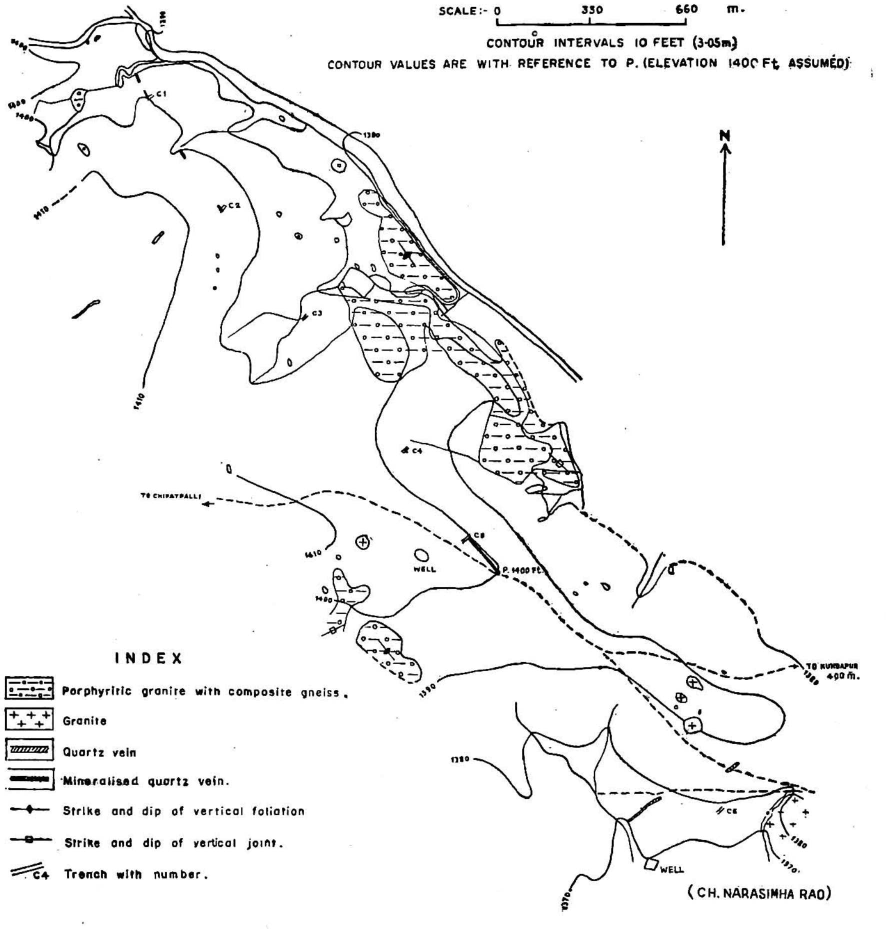
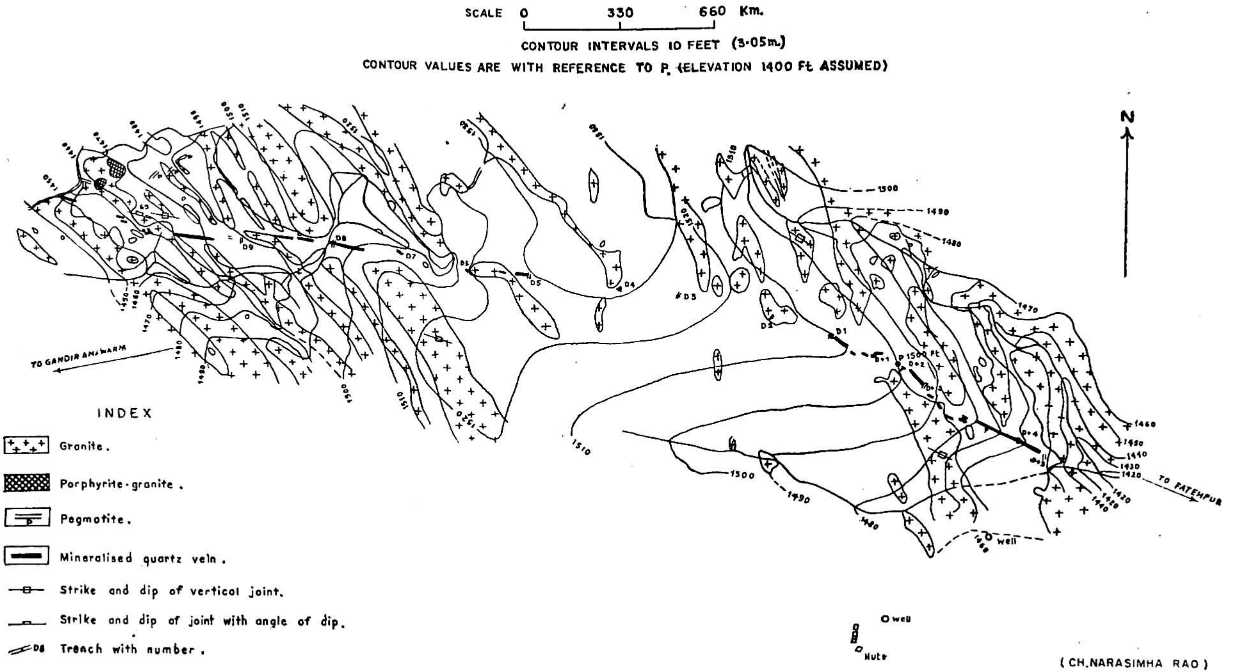


PLATE 12

GEOLOGICAL MAP OF THE MINERALISED ZONE SOUTH OF ABDUL NAGAW A RAM, WARANGAL DISTRICT, ANDHRA PRADESH



(CH. NARASIMHA RAO)

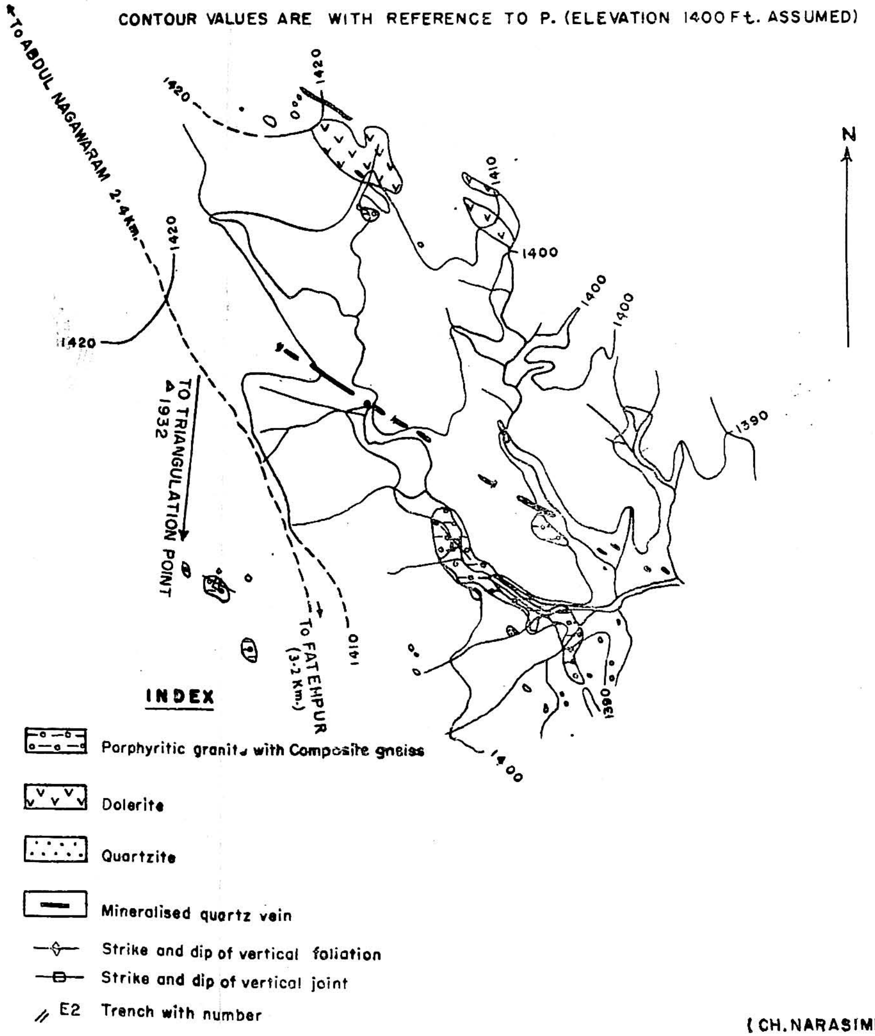
PLATE 13

GEOLOGICAL MAP OF THE MINERALISED ZONE SOUTH-EAST OF ABDUL NAGAWARAM, WARANGAL DISTRICT, ANDHRA PRADESH

SCALE:- 0 330 660 m.

CONTOUR INTERVALS 10 FEET (3·05 m)

CONTOUR VALUES ARE WITH REFERENCE TO P. (ELEVATION 1400 Ft. ASSUMED)



(CH. NARASIMHA RAO)

EXPLORATION FOR COPPER-ORE IN SINGHBHUM DISTRICT, BIHAR

BY

S. P. NAUTIYAL, S. K. BOSE,
J. G. K. MURTY AND R. S. SHARMA,
Geological Survey of India.

(With Plates 14-18)

ABSTRACT

Detailed structural mapping of the mineralised shear zones along 80 km. long patch of the belt between Khejurdari was carried out in recent years.

The control of ore localisation is both lithologic and structural. The copper mineralisation is in different rocks at different places. The mineralised zones are controlled by thrusts and associated shear zones and are along the foliation or bedding of the rock units. Trend of ore shoots coincide with the slip direction of shear zones, which is N.N.E. to north-east.

Apatite-magnetite and uranium-ore occur on the hanging walls of copper mineralisation and indicate lateral zoning along the copper belt.

Exploratory drilling has revealed the existence of several copper rich zones in Roam area. The mineralised zones struck during the course of drilling contain copper up to 5.1 per cent. There is a 6.7 m. thick zone with an average grade of ore containing over two per cent copper. There are possibilities of other zones being struck at greater depths. The strikewise extent of the mineralised zone is about 1,300 m.

In many other areas such as Rajdah, Ramchandra Pahar, Tama Pahar and Tamadungri, surface mapping and geochemical prospecting have indicated possibilities of rich copper zones.

INTRODUCTION

The production of copper in India is barely ten per cent of the consumption and almost all of it comes from the Mosaboni mines in the Singhbhum copper belt, Bihar. There exist a number of ancient workings in the stretch of 130 km. of the copper belt from Baharagora

(22°16′ : 86°43′) in the east to Mahulimurup (22°45′ : 85°53′) in the west. With a view to investigating the potentiality of the belt preliminary surveys by the Geological Survey of India were started in 1954. Systematic work was started from 1955 and it was intensified during the years 1956-61. The object of the investigation was to prepare large scale geological map of the mineralised shear zone and to collect structural data followed by geochemical prospecting. An area of about 400 sq. km. was mapped in the 80 km. long copper belt. Drilling in Roam-Sidheswar block has indicated sizable reserves of copper-ore.

Most of the field work was carried out by S/Shri S. K. Bose and J. G. K. Murty who were subsequently joined by S/Shri R. S. Sharma and D. D. Yellur. S/Shri M. K. Roy Chowdhury, K. Ganeshan, N.V.R. Subramanian and G. L. Wakhaloo were associated with the project in the initial stage. The senior author supervised the project work from 1956-61. The present paper deals with the work mainly carried out during this period.

Location

The area along the Singhbhum copper belt extends from Machbhandar (22°26′ : 86°33′) in the south-east to Mahulimurup in the west (Pl. 14a). This belt is within nine kilometres from the South Eastern Railway line passing through Dhalbhumgarh, Ghatsila, Rakha mines, Asanboni, Tatanagar and Sini and well connected by fair-weather roads from these railway stations.

Scope of Present work

The work of J. A. Dunn (1937) gives a comprehensive account of the geology and economic mineral deposits of the Singhbhum copper belt. Systematic geophysical surveys using S. P. and magnetic methods were carried out during the years 1950-55 and 1959-61 by the Geophysical section of the Geological Survey of India in this part of the copper belt. Intensive work was carried out in 80 km. long belt extending between Machbhandar on the south-east and Mahulimurup on the west during the period 1959-61. Structural mapping of an area of nearly 400 sq. km. on aerial photographs on 1 : 31,680 scale together with detailed mapping by plane table and telescopic alidade on 1 : 1,200 scale covering 25 sq. km. in Surda-Tamajuri, Surda (Putur), Laukesra (22°33′ : 86°27′), Rajdah-Narwa Pahar, Mahuldih, Roam-Sidheswar block and Ramchandra Pahar areas, were carried out.

Geochemical prospecting for copper was carried out in parts of the above area. About 12,800 m. of core from 136 boreholes drilled by the Department of Atomic Energy were examined. The boreholes were made in different areas between Patharghara and Keruyadungri. In parts of the 18th, 19th and 20th levels in the Mosaboni copper mines, a total of 1,825 running metres were mapped.

GEOLOGY

The major portion of Singhbhum district is occupied by rocks of Iron-ore series (Archaean) excepting for small patches of Tertiary rocks which occur in the south-eastern parts.

According to Dunn (1942), the rock types in the district are separated by a major thrust zone which extends eastward from Porhat through Chakradharpur, and Mosaboni from where it turns toward south-east into Mayurbhanj. The unmetamorphosed sequence occurring to the south of the thrust zone has been termed the Iron-ore stage while the rocks showing a greater degree of metamorphism and lying to the north of the thrust have been placed under the Chaibasa stage. The thrust zone has an overall length of 130 km. and forms the overfolded limb of a geanticline. The mineralisation is associated with the thrust zone and is marked by the presence of magnetite-apatite rock, quartz-chlorite-magnetite rock bearing copper lodes and radioactive minerals.

After the deposition of the Iron-ore series there was a large scale igneous activity of the ultrabasic and acid types.

The Dhanjori quartzitic sandstone and conglomerate demarcate the stratigraphical break in the southe[illegible]s. A succession of basic lava flows known as the Dalma ebb[illegible]h covering large areas. A succession of acid intrusives including the Arkasani soda-granite (granophyre) and the Singhbhum granite followed the igneous phase ending with the intrusion of the Newer dolerite.

The region between Rakha Mines and Mosaboni (22°32′ : 86°28′) exposes a variety of schistose rocks that have been affected strongly by structural disturbances amongst which is a very pronounced shear zone that is marked by copper mineralisation. The rocks show little similarity to those of the Iron-ore stage and resemble the rocks of the Dhanjori stage. The succession as worked out by the authors is as follows :—

North of Shear Zone

1. Tertiary gravel and laterite.
2. Mica-schist (with garnet and kyanite), lenses of hornblende-schist and ultrabasics.
3. Kyanite-quartz schist bearing dumortierite and tourmaline.

Shear Zone

1. Quartz-chlorite schist.
2. Albite-biotite-quartz schist with lenses of tourmaline-magnetite rock.
3. Soda-granite (copper lodes in Mosaboni etc.)
4. Tourmaline-chlorite-quartz rock (occasionally with quartzite breccia and conglomeratic at places) with copper lodes (Surda, Roam-Sidheswar and Rakha Mines).

South of Shear Zone

1. Chlorite and biotite-schist.
2. Quartzite.
3. Talc and chlorite-schist.
4. Quartzite.
5. Chlorite-schist with biotite and talc.
6. Meta-volcanics (biotite-chlorite schist, epidiorite and chlorite-actinolite schist) and altered ultrabasic rock.

The shear zone in Rakha Mines-Roam area is characterised by the chlorite-quartz rock with thin bands of quartzite breccia. In Patharghara-Mosaboni-Badia sector, it is marked by Albite-biotite-quartz schist and sheared granite, the latter bearing a number of copper lodes. In addition to the main shear zone, there are minor shear zones parallel to the main zone in the adjacent meta-volcanics at Dhobani (22°31′ : 86°27′) and also in the mica-schist near Laukesra (22°33′ : 86°27′) and Merhia villages.

The structure is complicated due to the intense folding and shearing all along the thrust zone. The general north-westerly strike in the Rakha Mines area gradually swerves to N.N.W. beyond Kendadih (22°35′ : 86°25′). Near Surda (22°33′ : 86°26′), the strike is approximately north-south. All the rock formations dip towards north-east to east at 40° and 45°. The structural pattern of the area is mainly controlled by a series of isoclinal folds. Axial plane cleavage developed during this folding movement, later served as shear surfaces, through which mineralising solutions could move up.

Near Rakha Mines, the regional fold axes of the isoclinal folds plunge at low angles towards the south-east whereas, near Kendadih and Surda the fold axes have a gentle N.N.W. plunge. There are minor undulations in the fold axes. Another fold pattern is recognised, diagonal to the regional fold axis trending N.E. to N.N.E. and these form open anticlines and synclines.

A number of post copper mineralisation transverse faults trending north-west and N.N.E. run across the area. Cross and oblique joints, sometimes with quartz vein fillings are ubiquitous; their development being more intense in the competent rocks.

MINERALISATION

Three distinct periods of mineralisation are apparent (a) apatite-magnetite mineralisation, (b) uranium mineralisation and (c) sulphide mineralisation. The earlier oxide phase is separated by the later sulphide phase by a prolonged period of biotitisation and chloritisation.

The main ore mineral is chalcopyrite with pyrite, pyrrhotite, pentlandite and minor violarite and millerite. Apatite and magnetite are frequently associated with the lodes. The gangue includes chlorite, biotite, quartz and tourmaline.

The control of ore localisation is mainly structural, but lithology has also played an important role. The mineralised zones are controlled by thrusts and associated shear zones. The copper mineralisation of Mosaboni region may be considered to be a shear zone filling. The granite is very heavily shattered. Numerous parallel to sub-parallel fractures were developed in the granite and adjacent metavolcanics during the tectonic movements. Sulphide minerals were deposited in narrow zones of dark green chlorite rock showing pronounced schistosity. The schist bands occur in soda-granite as seen in Mosaboni and Badia mines (22°29′ : 86°28′). The trend of the ore shoots coincides with slip direction (N.N.E. to N.E.) of shear zones. It is also likely that cross folding of an *en echelon* pattern may have had control on ore localisation as is evidenced in Mosaboni and Rakha Mines. There is a general sinistral pattern of folding and disposition of copper lodes which is found to change suddenly into a dextral pattern beyond Jaduguda and Turukocha mines.

The copper mineralisation occurs in soda-granite at Mosaboni, in epidiorite in Dhobani-Chirudih sector, in quartz rock, quartzite breccia and quartz-chlorite rock in Rakha Mines-Roam area, in chlorite-schist in Rajdah and Ramchandra Pahar blocks and quartz-mica schist around Kendadih.

DESCRIPTION OF INDIVIDUAL DEPOSITS

(a) **Roam-Sidheswar (22°37′ : 86°24′) and Rakha Mines (22°38′ : 86°27′) blocks (Pl. 14).**

The Roam-Sidheswar block in the central portion of the Singhbhum copper belt, is about two kilometres south-east of the old Rakha Mines. The Rakha Mines area is one of the earliest ones to be prospected in this belt. The Rakha lode appears to be more than 600 m. in length. The Cape Copper Company carried out prospecting and development of this lode between 1914 and 1922. The main lode was developed to the depth of 274.13 m. along the dip. The company produced 182,985 tonnes of ore assaying on an average 3.8 per cent copper.

The strike of the formations in Roam-Rakha sector is N.40°W. to N.50°W. with dips of 35° to 50° towards north-east. The rock types noticed from north-east to south-west are mica-schist, biotite-chlorite schist, felspathic quartz-biotite schist, chlorite-quartz rock with bands of quartzite breccia and quartz tourmaline rock, quartzites, epidiorites and ultrabasic rocks.

The strike length of Roam-Sidheswar mineralised zone containing the main lode and other subsidiary lodes is about 1,300 m. The surface indications of copper are (i) chlorite rich zones in massive quartz-biotite-chlorite rock with variable tourmaline and magnetite, (ii) crushed zones of quartz veins often stained with hydrated iron oxides and containing thin magnetite veins (iii) quartzite breccia, (iv) malachite splashes near the mineralised zones and (v) ill defined gossan zones. The old workings (shallow prospecting pits, vertical shafts and winzes) though localised in certain zones, are quite prominent and extensive. The width of the mineralised zones generally varies from 3 to 12 m. but some minor zones of about one metre width have also been noticed.

The main host rock for copper is a granular quartz-biotite-chlorite rock. Minor mineralisation is also noticed in quartzite and quartzite breccia.

Geochemical Prospecting:-Detailed geochemical prospecting was carried out and the soil samples were collected from varying depths of 30—40 cm. at interval of 15 m. In all 200 soil samples were collected along 8 traverse lines, spaced 60m. apart. The copper value ranges from 50 to 4,000 p.p.m. or above and generally the high values are 10 to 40 times the background values. High geochemical anomaly zones correspond to the lode zone or suspected mineralised zones or lines of old workings and can thus be correlated with the surface indications, where present.

The presence of the 'main lode' is indicated in most of the traverse lines by varying 'peak' values and such 'peaks' are picked up along the strike and correlated with the available surface data. The hanging wall and foot wall zones appear to be discontinuous and this is also confirmed by test drilling.

Mineralisation:- The chief ore mineral is chalcopyrite. The other primary sulphides are pyrite and pyrrhotite. Some secondary copper-ore such as malachite is seen up to 40 m. inclined depth from the surface, in the drill cores. Secondary silica and calcite veins are also noticed along fracture and bedding planes and vugs.

The mineralisation is mainly in the form of disseminations and appears to be influenced by the bedding or foliation of the rocks.

There are several mineralised fractures cutting across the schistosity but these are comparatively of less importance. Replacement appears to be more common than *fissure fillings*.

(b) **Rajdah (22°41′ : 86°17′) area (Pl. 14A)**

In the Rajdah-Narwa Pahar area (sheet 73 J/6) an area of 588,800 sq. m. was geologically mapped on 1 : 1,200 scale. The rock types are *sericite-chlorite schist, sericite-schist, chlorite-schist, chlorite-*quartzite, sericite-phyllite, actinolite-chlorite schist, quartzite breccia in chlorite-schist and quartzite. The main rock types of the shear zone are sericite-chlorite schist and quartz-chlorite schist, thickly impregnated with magnetite and apatite.

The strike of the rock formations is N.W.-S.E. and the dips are from 45° to 55° towards north-east. Two sets of joints are developed

in quartz-chlorite schist and quartzites. One set trends N.N.W.—S.S.E. to N.W.-S.E. and dips toward south-west or north-east at angles varying from 45° to 60°; the other set trends N.E. - S.W. to E.N.E.—W.S.W. and dips toward north-west or south-east, at angles varying from 45° to sub-vertical. Lineations are best developed by groovings on the bedding planes of quartzite, corrugation in the schists which trend N. 55° W to N. 65° W. and are sub-horizontal, minor folds and mineral parallelism. The drag folds plunge N.W. to N.N.W. with amounts varying from 30° to 40°. A few dextral folds are also seen in the quartzite plunging S.E. to E.S E. from 20° to 25°.

The mineralised zones in this area are characterised by (a) a zone of crushed and brecciated quartz vein of variable width along which most of the old workings are localised, (b) malachite stains on the outcrops near the mineralised zones, and (c) spongy limonitic patches, possibly due to the alteration of the sulphides.

Copper mineralisation is mainly confined to the sericite-chlorite schist. Apatite-magnetite mineralisation characterises the shear zone and is also noticed in other rock types such as quartzite breccia, muscovite-schists and quartzites. The most important zones are along the quartzite breccia.

Geochemical Prospecting :—The soil samples did not show any high values for copper in this area except two sporadic values of 750 p.p.m. and 1,000 p.p.m. without much of a spread. The only promising area is Rajdah-Gara *nala* sector where anomalies of a higher order have been picked up. Subsequently further prospecting was done on a closed grid pattern. The copper anomalies range from 400 to 4,000 p.p.m. and the width of the zones varies from 7.5 to 60 m. The major anomaly zones correspond to the lode horizon or lines of old workings but are not continuous along the strike. There appears to be some shift towards the foot wall showing an *en echelon* arrangement of the ore shoots.

Economic prospects :—The Rajdah lode was prospected by the Hindusthan Copper Company in 1862-64 by an incline-shaft in the sericite-chlorite schist but did not meet the lode. Possibly it was not extended to sufficient depth. However, sn the vertical shaft only two minor impregnations were met with at depths of 14.4 and 9 m. respectively, Recently, geophysical surveys have been carried out in this

area, without any encouraging results.

The limited extent of the Rajdah lode is probably due to the lateral zoning on both the sides where the apatite-magnetite veins have impregnated the shear zone. The old workings in the Rajdah area are small and most probably there are a number of thin veins. The strike length of the Rajdah mineralised zone is about 700 m. out of which about 610 m. is on the eastern side of Gara *nala*. The width is about 3 - 4.5 m.

(c) Ramchandra Pahar (22°43′ : 86°13′) area (Pl. 15)

In the Ramchandra Pahar area probable existence of rich copper lodes are inferred on the basis of geochemical prospecting in an area of 0.7 million sq. m. and the main anomaly runs along the line of the old workings.

The main rock types are the chlorite-sericite-quartz schist and its variants, with varying proportions of magnetite, chlorite, quartz and apatite; silicified zones, schistose granite, mylonitic and cataclastic chlorite-quartz rock, brecciated quartzite and quartz-schist. Some of these are rich in apatite and magnetite veins and disseminations while a few show favourable signs of copper mineralisation.

The strike of the formation is N.40°W.- S.40°E. to N.80°W.- S.80°-E. and the dip is from 30° to 70° in N.10°E. to N.50°E. directions. Joints are best developed in the silicified zones and quartz-chlorite rock. They trend N.W. - S.E. and N.E. - S.W. and at 40° to 70° towards N.E. and S.W. respectively. Groove lineations are best developed and they trend N. 50°E. The minor drag folds plunge due N.W. to N.N.W. and N.E. at about 30° to 45°.

The rocks are intensely silicified, brecciated and pucker[illegible] The folds have been refolded, a feature indicated by shallo[illegible]nd steepening of foliation dip. The migration of the ore-bearing [illegible]tions is possibly syntectonic.

In Ramchandra Pahar area five distinct mineralised horizons have been mapped varying in width from 5 to 40 m. and with a traceable strike extent of 50 to 350 m.

Geochemical Prospecting :-Within this area, only the Ramchandra hill (.1101) and Nandup North (22°42′ : 86°12′) have indicated the possibilitity of the existence of copper lodes. In the rest of the area there is a thick alluvial cover and no copper bearing horizons have been located.

The detailed grid pattern geochemical prospecting carried out in Ramchandra Pahar hill area has shown very encouraging results. Out of the 1,251 soil samples collected, more than half have shown values over 500 p.p.m. of copper. The general slope of the hill portion is about 25° and this point has been taken into consideration with regard to the influence on copper values owing to the downward migration and dispersion of copper ions. This work has indicated the presence of four major copper rich horizons, running almost parallel but in an *en echelon* pattern with a minimum strike length of 180 m. and a maximum of 500 m. The rocks are intensely brecciated and silicified, a feature quite congenial for localisation of mineralising solutions.

Ancient Workings :- A number of old workings are seen on the top and along the northern slope of the Ramchandra Pahar hill. Most of them are very wide and deep and some appear to have been interconnected. In some of these, winzes are well developed. Most of the old pits are completely filled up. On the top portion of the hill there are five openings.

(d) Mahuldih (22°44′ : 86°09′) area (Pl. 16)

Mahuldih is situated about eight kilometres, south-west of Tatanagar railway station The mineralised area is about 400 m. south-east of Mahuldih village.

Geochemical anomaly :- During the course of geochemical prospecting in this area, the reconnaissance traverse line No. 2 gave a high anomaly 'spread' of 390 m. with values ranging from 1,000 to more than 4,000 p.p.m. of copper. Following this, a closer grid-pattern prospecting was started with line interval of 30 m. and sample interval at 7.5 m. In all, about 2,000 soil samples were collected, of which 1,138 were analysed in the field itself. The higher values were persistent for over a strike length of 600 m. (300 m. on either side of line No. 2) with 'spreads' of varying widths. In general the Mahuldih hill with its 600 m. strike length and about 480 m. of width appeared

to be quite promising. Line no. 2 appeared to pass through the central portion of the anomaly zone, wherefrom soil samples were collected from 0.6 m. depth at 7.5 m. interval for analysis. The samples on analysis gave uniformly more than 4,000 p.p.m. of copper. Three fourth of the samples analysed gave values ranging from 2,100 to 4,000 p.p.m. while the rest showed values ranging from 4,000 to 8,700 p.p.m. of copper

Geological features:—The high 'anomaly' area was mapped on a scale of 1:1,200 covering about 5,63,000 sq. m. The rock types from north-east to south-west and along the prospecting line no. 2 are mainly chlorite-sericite schists with varying proportions of magnetite and quartz, talc-sericite-chlorite schist, phyllite, cherty quartzite and banded quartzite. The quartz-chlorite-sericite schist contains varying proportion of chlorite and sericite, the two being gradational. The chlorite-schist is rich in magnetite whereas, the sericite rich portions are poor in magnetite. It is often impregnated with quartz veins which are parallel to foliation. The quartz veins are generally lenticular in shape and show pinching and swelling. The talc-chlorite-sericite schist occurring on the footwall of the magnetite bearing chlorite-schist has an outcrop width varying from about one to nine metres. The contact with the overlying rocks is gradational and it appears to pinch out in both directions, occurring as a lens shaped body. The rock is profusely stained with secondary copper-ores. Quartzite occupies the southern part of the area. Its hanging wall contact is often concealed by the quartzite debris. It also pinches out along the strike in both the directions. It is essentially a banded rock containing intercalations of sericite-chlorite schist and sericite-quartz schist. The quartzite varies from massive, well laminated to schistose type and is well jointed. Though bedding is well recognisable, foliation becomes prominent when sericite is present. The width of the quartzite is variable. It appears to be of secondary origin as it passes laterally into schist.

The strike of the rock formations in this area varies from N. 45° to 65° W.—S.45° to 65° E. dipping at 40°—55° N.E. The foliation attitudes and trend of different rock units show that they are more or less parallel without any appreciable deviation. The dip is uniformly towards north-east. The formations are refolded and crinckled. Drag folds are quite common and the quartz veins and quartzi-

tic bands are folded with the schist. The plunge of these folds varies, the most common direction being N. 50° W.

Surface Indications of Mineralisation:—The surface indications of copper mineralisation in this area are best exhibited by limonite patches and ill developed gossan zones and by staining of the outcrops by secondary copper-ores such as malachite and azurite. There are also copious stains of bornite associated with malachite. The old workings are shallow and are partly filled up. The mineralised zone here appears to dip N. 45° to 50° E. Copper slag heaps in the eastern part of the area suggest that the ore had been exploited in the past.

(e) Tama Dungri (22° 45′: 86° 02′) area (Pl.17)

The area is near Simulbera, about one kilometre W.S.W. of Rangamatia (sheet 73 I/2).

The rock types are mainly phyllite, quartz-talc schist, sericite-chlorite schist, quartz-tourmaline rock and quartz-schist. Several quartz veins cut across these formations.

In the southern part of the area the phyllites are predominantly composed of fine-to medium-grained quartz and sericite and showing at places some tourmaline and magnetite. In the south-eastern part, the dominant rock is quartz-talc schist. There are a number of quartzite bands within the schists. The schistose variety is traversed by a number of small quartz veins which mainly follow the foliation planes of the host rock and also cut across the quartzite bands occurring within the schist.

The northern part is occupied by the sericite-chlorite schist, sericite being the dominant mineral. Some of them contain small siliceous nodules which stand out prominently on weathering. This formation is also cut by numerous quartz veins.

The quartz-tourmaline rock, exposed in the central part is medium to fine-grained and dark coloured. Quartz veins cut this rock in an anastomosing way, although they mainly follow the joint planes. Some of the varieties contain aggregates of short prismatic crystals of tourmaline.

The quartz-schist occurs as a narrow band in the western part of the area. At places it shows a banded appearance. The percentage of magnetite varies from place to place, and at times this mineral forms as much as 50 per cent of the rock mass.

The strike of the formations in the area takes swing from west to east. It is N. 70° W.—S. 70° E. in the western part, but swings to N. 70° E.—S. 70° W. in the eastern sector. The dips are northerly and vary in amount from 40° to 50°. The formations specially the quartz-tourmaline rock are well jointed. Minor folds are developed in the talc-schist, plunging from 20° to 35°, in a direction varying from N. 10° E. to N. 60° E.

During the folding and shearing movements and possibly later, this area appears to have been subjected to intense silicification and tourmalinisation, giving rise to the quartz-schists, quartz veins and tourmaline-quartz rock.

Old Workings :—Old workings for copper-ore including a number of vertical shafts, inclines and shallow pits are seen on the ridges near Simulbera. The shafts sunk are vertical and placed close to the footwall of the mineralised zones with the result that the mineralised zone was not encountered. Some of the pits are placed on the quartz-schist. Practically all the old workings are now filled up and it is impossible to examine them in any detail.

Mineralisation:— The copper mineralised zones are characterised by (a) malachite splashes (b) limonitic patches and (c) presence of crushed quartz veins. The strike length of the Simulbera copper mineralised zone is about 460 m. Its width is variable but on an average it is six metres.

Quartz-schists, quartz-tourmaline rock and sericite-chlorite schist are the main host rock types in this area. The talc-schist shows very minor indications of copper mineralisation. The sericite-phyllites are not mineralised.

EXPLORATORY DRILLING FOR COPPER

Mahuldih area

The area was further explored by putting down three test drill holes with an aggregate metreage of 667 m. Exploratory drilling was started in February, 1960 and completed in July, 1961.

Borehole No. 1 :—A vertical borehole MH—I was located at 91.4 m. from the O station on line no. 2, and was driven to a depth of 263. 77m.

Copper mineralisation occurs in the form of disseminations and slightly concentrated zones. The host rock is a quartz-chlorite-sericite-magnetite schist with quartz in the form of veins and segregations. The schist itself has many variants with varying concentrations of chlorite, sericite and magnetite. The various mineralised zones are as follows :

	Borehole run (in metres)	*Thickness* (in metres)	*Average* Copper percentage
	21.15—22.27	1.12	0.69
Zone	26.39—27.99	1.60	0.97
I	32.35—33.68	1.33	0.72
	37.49—39.26	1.77	1.14
	162.12—162.86	0.74	0.10
	162.86—162.99	0.13	1.14
Zone	162.99—163.11	0.12	0.19
II	163.11—163.67	0.56	0.10
	163.67—163.90	0.23	3.91
	163.90—164.20	0.30	0.10
	164.20—164.46	0.26	0.10

Average for 2.34 m. (162.12—164.46)=0.59 per cent copper

Average for 1.34 m. (162.86—164.20)=0.85 —do—

It is seen from the analytical results that the mineralised zones in borehole MH—1 do not have any high grade ores. The mineralised zone of 1.77 m. (37.49—39.26 m.) having 1.14 per cent copper needs further exploration both along strike and dip.

Borehole No. 2 :—The second borehole site was selected at a distance of 150·57 m. in N. 54° E. direction from the site of borehole MH—1. It was extended to a depth of 292·22 m. Mineralisation in this borehole is in the form of fine disseminations in quartz-chlorite-sericite-magnetite schist. The following are some of the sulphide zones met with in the borehole.

Borehole run (in metres)	*Thickness of sulphide zones* (in metres)
130·50—134.11	3·61
173·81—182·14	8·33
189.73—218·23	28·50
221·08—226·33	5·25

Along with the chlorite-schist, some felspathic schist was also met with in this borehole from 58·21 to 72.54 m.

Borehole No. 3 :—The third borehole MH—3 was placed at a distance of 243·83 m. from borehole MH—1 in 210° direction. This was a 45° angle hole and was extended to a depth of 110.6 m. The sulphide mineralisation was found to be in the form of fine disseminations. Actually the borehole seems to have passed through old stopes between 7 and 12 m. and again 12 and 27 m. Quartz-chlorite-sericite-magnetite schist is the host rock.

Roam-Sidheswar block

Introduction :—Exploratory drilling for copper was started in January 1961. The area is situated about 1,700 m. S.E. of the main Rakha shaft and the boreholes are placed along the same strike, just on the hanging wall of the mineralised zones. Several copper rich zones have been encountered during the course of exploratory drilling. More intensive prospecting by drilling is in progress in this area.

Analysis of the Borehole Results :—The copper mineralisation is mainly confined to the tourmaline and magnetite bearing chlorite-quartz rock (schistosity ill defined), quartzite breccia (along which some old workings are also localised on the surface) and biotite-chlorite schist. The footwall quartzite also shows mineralisation along fractures, associated with magnetite and chlorite veins, and bedding planes but appear to be very sporadic. The chlorite rich zones are found to contain better grade of ore than biotite rich patch in the schist.

The mineralisation is mainly in the form of disseminations, sparse to good, and follows the foliation or bedding of the rock types. There are several mineralised fractures of less importance cutting across the foliation. Replacement phenomenon appears to be more common than the fissure filling. Several solid patches of chalcopyrite are seen, some up to 40 cm. in thickness and assaying 11·65 per cent copper.

The chief ore mineral is chalcopyrite. The other primary sulphides are pyrite and pyrrhotite. Some secondary copper-ore minerals are also seen up to about two metres below the surface but no oxidised mineral is seen. Secondary silica and calcite veins are seen at some places along fractures and bedding planes. The dip of the lode appears to be about 45° in northerly direction.

Brief Account of the Mineralised Zones (*Pl. 18*) :—The results of analyses and the average grade of different copper zones as encountered in borehole RMA—1 and 2 are given in Table 1.

It may be mentioned here that as per the Indian Copper Corporation specification, the payable ore is 1·88 per cent copper over a stoping width of 100 cm. but lower grades are also being worked at times.

TABLE—1

Serial No.	From (metres)	To (metres)	Thickness (metres)	Average grade Cu %
Borehole RMA—1				
1.	12.29	16.46	4.17	0.69
1a.	14.79	16.46	1.67	0.88
2.	16.46	20.87	4.41	0.40
3.	22.32	25.77	3.45	1.22
3a.	22.32	24.38	2.06	0.80
3b.	24.38	25.77	1.39	1.92
4.	35.77	27.42	1.65	0.60
5.	28.75	30.65	1.90	0.68
6.	30.65	32.25	1.60	1.38
7.	45.97	49.37	3.47	0.57 (Sludge)
8.	49.37	50.67	1.30	4.38
9.	58.65	62.63	3.98	0.66 (Sludge)
10.	88.20	88.80	06.0	0.46
11.	91.95	92.62	0.67	0.34

Borehole RMA—2 :				
1.	15.24	17.75	2.51	0.92
2.	20.85	22.12	1.27	0.58
	29.30	30.11	0.81	0.77
4.	39.22	44.69	5.47	2.00
5.	46.10	47.37	1.27	2.10
6.	86.33	87.34	1.01	1.88
7.	88.64	89.27	0.63	1.12
8.	92.51	94.91	2.40	0.52
9.	103.18	103.66	0.48	1.03
10.	104.28	106.22	1.94	2.01
11.	106.22	107.28	1.06	0.74
12.	108.00	109.68	1.68	0.93
13.	109.68	110.93	1.25	2.42
14.	114.50	115.44	0.94	0.82
15.	123.44	126.86	3.42	1.03
16.	127.86	129.02	1.16	1.14

Particular reference may be made to the combined 9.93 m. zone, running from 22.32 to 32.25 m, (Borehole RMA—1) which if proved along the strike and depth in successive boreholes, may be worth trying for further exploration. In borehole—1 there are eleven zones of which nine are sub-zones and only two are payable (No. 3b and 8)) as per the Indian Copper Corporation standard. But, as stated above, further exploration by drilling will help to determine the nature of other zones.

In borehole No.2 there are four major zones with an average copper content of two per cent or slightly more and one zone having

1.88 per cent copper One of the major zones, averaging two per cent copper met with at an inclined depth of 39.22 m. is 5.47 m. thick followed by another zone having a thickness of 1.27 m. (average 2.1 per eent copper) is separated from the above by a poor zone of 1.01 m. This zone appears to continue 240 m. along the strike which is proved by drilling and found to continue on the surface for a fairly long distance as evidenced by old workings and other surface indications. This zone contains several solid veins of sulphide of varying thickness.

Sub-zones in borehole RMA—2 (nine in all) on further examination may be correlated with other zones in subsequent holes; only then their potentialities can be properly assessed.

Ore Reserves:- The reserve of copper-ore as given below may be taken as tentative, pending further exploration by drilling. The reserves have been calculated assuming the following:-

(a) The ore shoots are continuous up to depth of 300 m. It has been proved by mining operations at the Mosaboni mines that the ore shoots continue beyond a depth of 750 m. Similarly, the ore shoots in the Rakha Mines area, contiguous to the Roam-Sidheswar block, had also been mined down to a depth of about 300 m. in the past and it is presumed that the ore shoots are likely to continue to greater depths

(b) The area of influence of a borehole is 60 m. which is half the distance between two boreholes placed roughly along the same strike.

(c) The minimum workable thickness is one metre.

(d) The cut-off grade of copper is 0.8 per cent.

(e) Zones of equal assay values have been assumed to be continuous along the strike pending collection of further data by subsequent exploration regarding the nature of ore bodies.

(f) The strike length of the major mineralised zones has been taken at 240 m. and for smaller zones only 120 m.

Indicated and inferred reserves up to 300 m. depth from 150 m. R.L.

		Million tonnes
(1) Ore containing 2.0 % Cu and above	—	1·33 Approx.
(2) Ore containing 1.5 % Cu and above	—	1.1 ,,
(3) Ore containing 0.8 % Cu and above	—	1.67 ,,
	Total	4. 10 Approx.

Thus the total expected reserve of all grades for a strike length of approximately 250 m. and depth of 300 m. is 4.10 million tonnes. But the reserves are likely to be much higher for the entire Roam-Sidheswar block which may be of the order of 15 million tonnes of all grades (0.8 per cent Cu and above) up to a depth of 300 m. assuming the ore-body to extend over the entire strike length of 1,300 m. of the copper mineralised zones in this area.

Subsequent exploration which is in progress in this area has proved that the continuity of the mineralised zones, strike and dipwise is much greater and the reserves are substantially high.

CONCLUSIONS

The results of the present investigations have indicated a few copper-rich areas such as those at Rajdah, Ramchandra Pahar and Tamadungri which need further prospecting by drilling. Of these, Ramchandra Pahar appears to be the most promising and should be given first priority. Small size deposits of copper-ore may be expected at Rajdah and Tamadungri. Copper mineralisation at Mahuldih appears to be disseminated and it needs further exploration by drilling.

The results of exploratory drilling in Roam area have been very encouraging and further exploration now in progress is expected to prove substantial ore reserves of various grades in this area. The tentative reserves of ore in this area constitute a potential prospect. The Roam-Sidheswar and the contiguous Rakha Mines block may be simultaneously developed so that these can ultimately be worked as a single mine.

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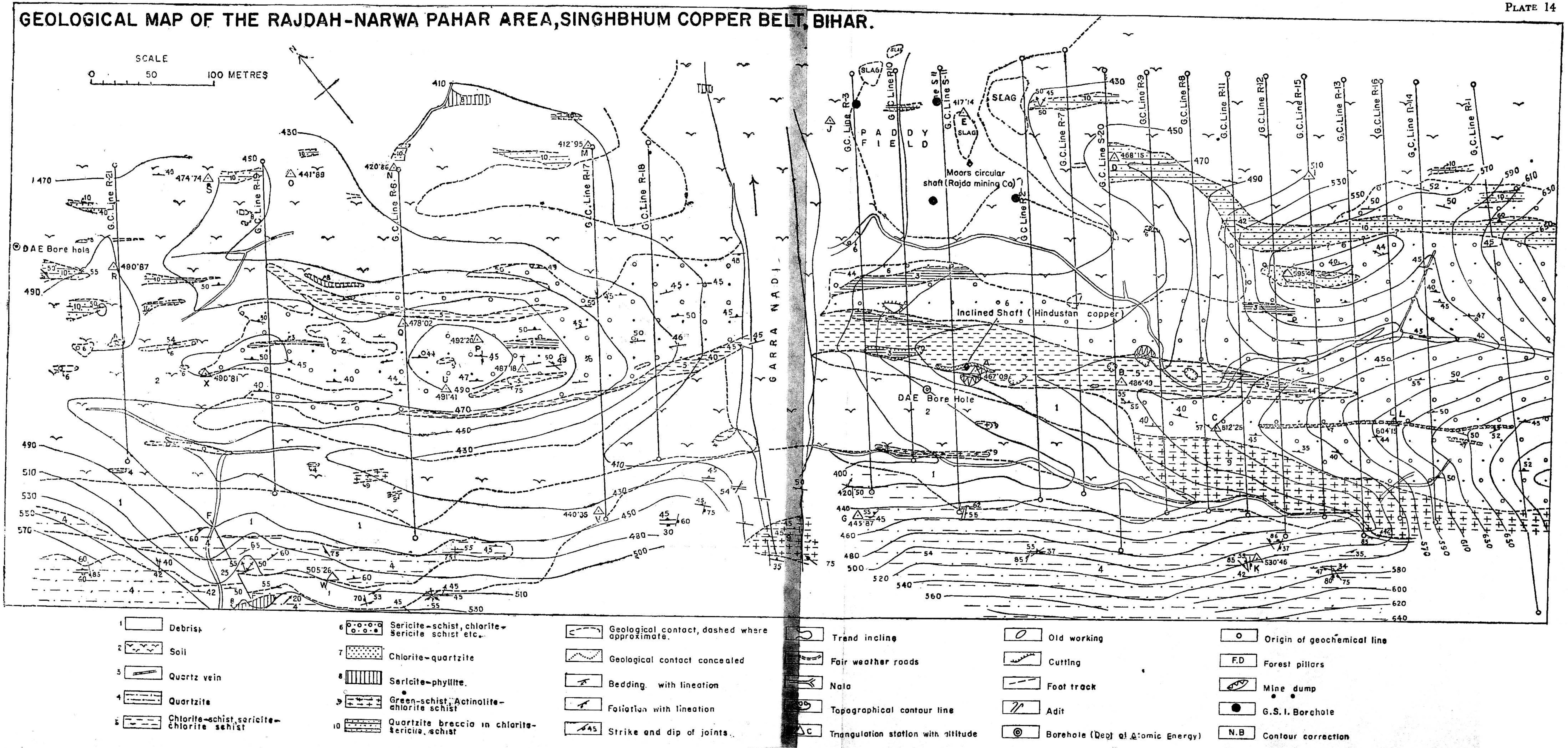
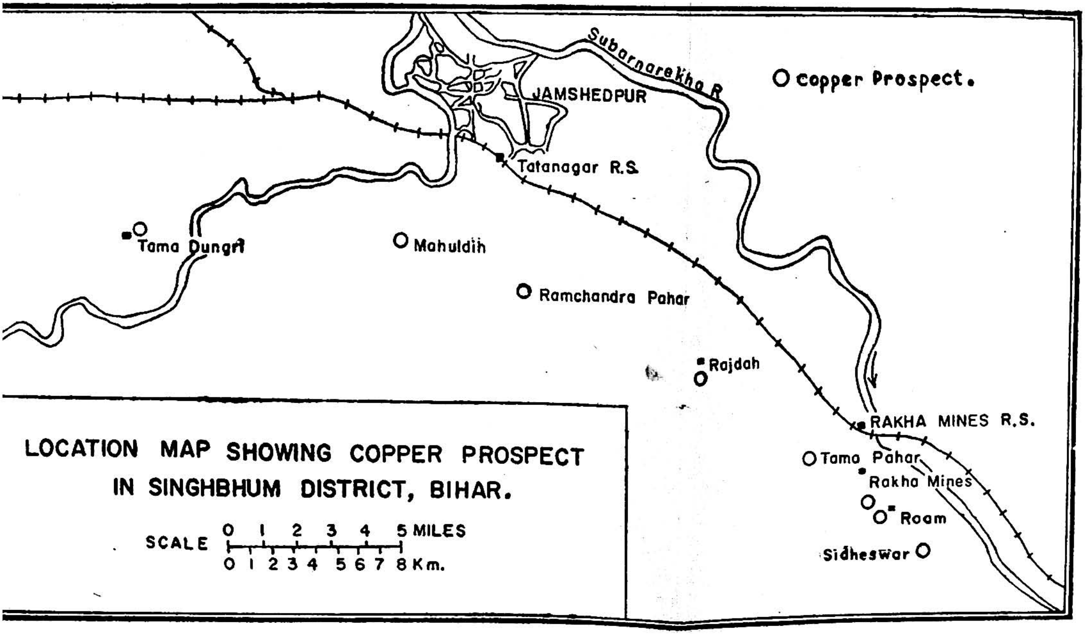
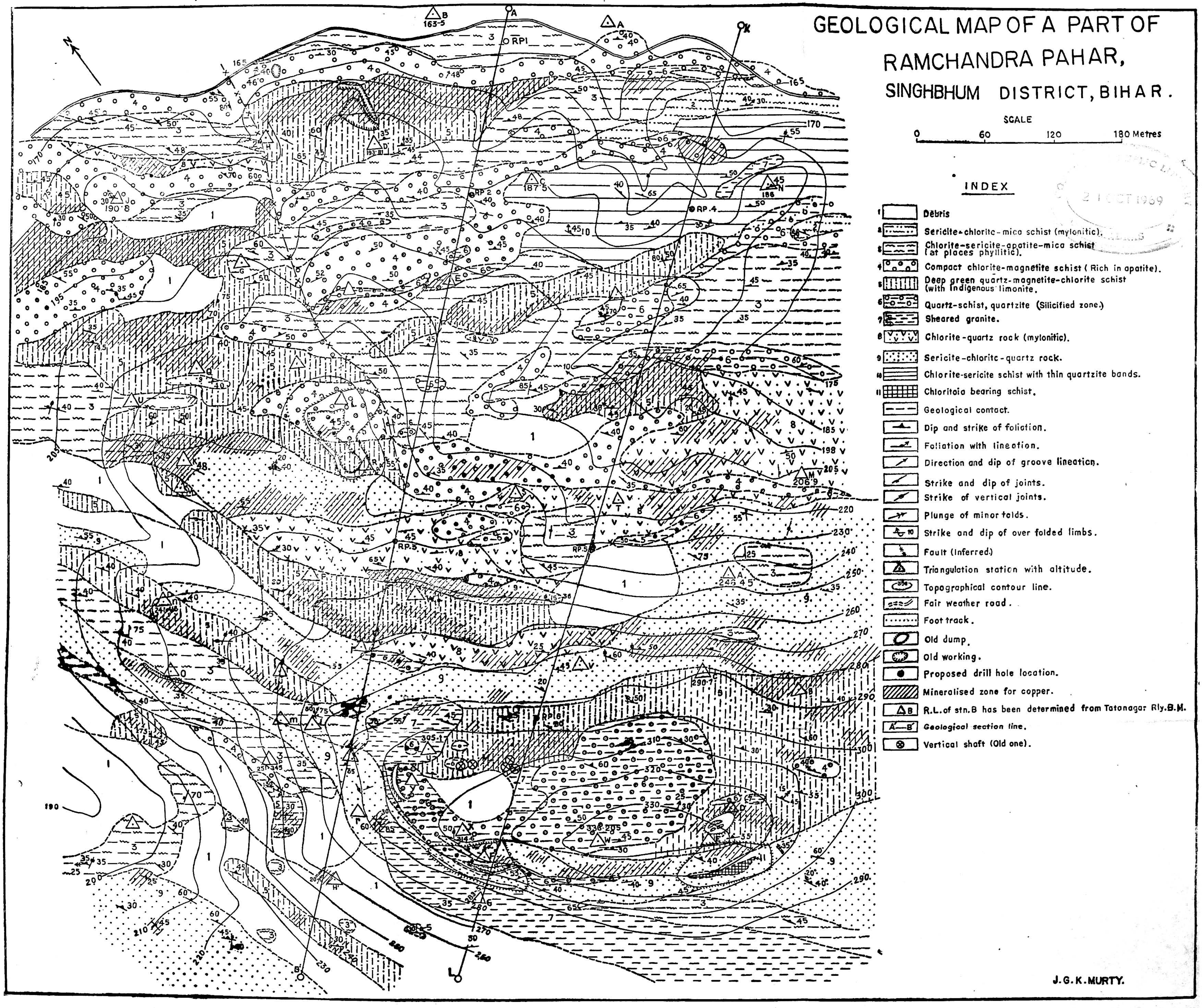

GEOLOGICAL MAP OF THE RAJDAH-NARWA PAHAR AREA, SINGHBHUM COPPER BELT, BIHAR.
SCALE
0 50 100 METRES
GARRA NADI
PADDY FIELD
SLAG
Moors circular shaft (Rajda mining Co)
Inclined Shaft (Hindustan copper)
DAE Bore hole
DAE Bore Hole
G.C. Line R-21
G.C. Line R-19
G.C. Line R-6
G.C. Line R-17
G.C. Line R-18
G.C. Line R-3
G.C. Line R-10
G.C. Line S-11
G.C. Line R-2
G.C. Line R-7
G.C. Line S-20
G.C. Line R-9
G.C. Line R-8
G.C. Line R-11
G.C. Line R-12
G.C. Line R-15
G.C. Line R-13
G.C. Line R-16
G.C. Line R-14
G.C. Line R-1
1 Debris
2 Soil
3 Quartz vein
4 Quartzite
5 Chlorite-schist, sericite-chlorite schist
6 Sericite-schist, chlorite-sericite schist etc.
7 Chlorite-quartzite
8 Sericite-phyllite
9 Green-schist, Actinolite-chlorite schist
10 Quartzite breccia in chlorite-sericite schist
Geological contact, dashed where approximate
Geological contact concealed
Bedding with lineation
Foliation with lineation
Strike and dip of joints
Trend incline
Fair weather roads
Nala
Topographical contour line
Triangulation station with altitude
Old working
Cutting
Foot track
Adit
Borehole (Dept of Atomic Energy)
Origin of geochemical line
F.D Forest pillars
Mine dump
G.S.I. Borehole
N.B Contour correction

PLATE 14A


Subarnarekha R.
JAMSHEDPUR
Tatanagar R.S.
O copper Prospect.
Tama Dungri
Mahuldih
Ramchandra Pahar
Rajdah
RAKHA MINES R.S.
Tama Pahar
Rakha Mines
Roam
Sidheswar
LOCATION MAP SHOWING COPPER PROSPECT
IN SINGHBHUM DISTRICT, BIHAR.
SCALE
0 1 2 3 4 5 MILES
0 1 2 3 4 5 6 7 8 Km.


GEOLOGICAL MAP OF A PART OF
RAMCHANDRA PAHAR,
SINGHBHUM DISTRICT, BIHAR.
SCALE
0 60 120 180 Metres
INDEX
1 Debris
2 Sericite-chlorite-mica schist (mylonitic).
3 Chlorite-sericite-apatite-mica schist (at places phyllitic).
4 Compact chlorite-magnetite schist (Rich in apatite).
5 Deep green quartz-magnetite-chlorite schist (with indigenous limonite.
6 Quartz-schist, quartzite (Silicified zone.)
7 Sheared granite.
8 Chlorite-quartz rock (mylonitic).
9 Sericite-chlorite-quartz rock.
10 Chlorite-sericite schist with thin quartzite bands.
11 Chloritoid bearing schist.
Geological contact.
Dip and strike of foliation.
Foliation with lineation.
Direction and dip of groove lineation.
Strike and dip of joints.
Strike of vertical joints.
Plunge of minor folds.
Strike and dip of over folded limbs.
Fault (Inferred)
Triangulation station with altitude.
Topographical contour line.
Fair weather road.
Foot track.
Old dump.
Old working.
Proposed drill hole location.
Mineralised zone for copper.
R.L. of stn. B has been determined from Tatanagar Rly. B.M.
Geological section line.
Vertical shaft (Old one).
J. G. K. MURTY.

GEOLOGICAL MAP OF PART OF BHALOBASA AREA ABOUT 400 M. SOUTH-EAST OF MAHULDIH, SINGHBHUM DIST., BIHAR.

SCALE

0 20 40 100 150 METRES

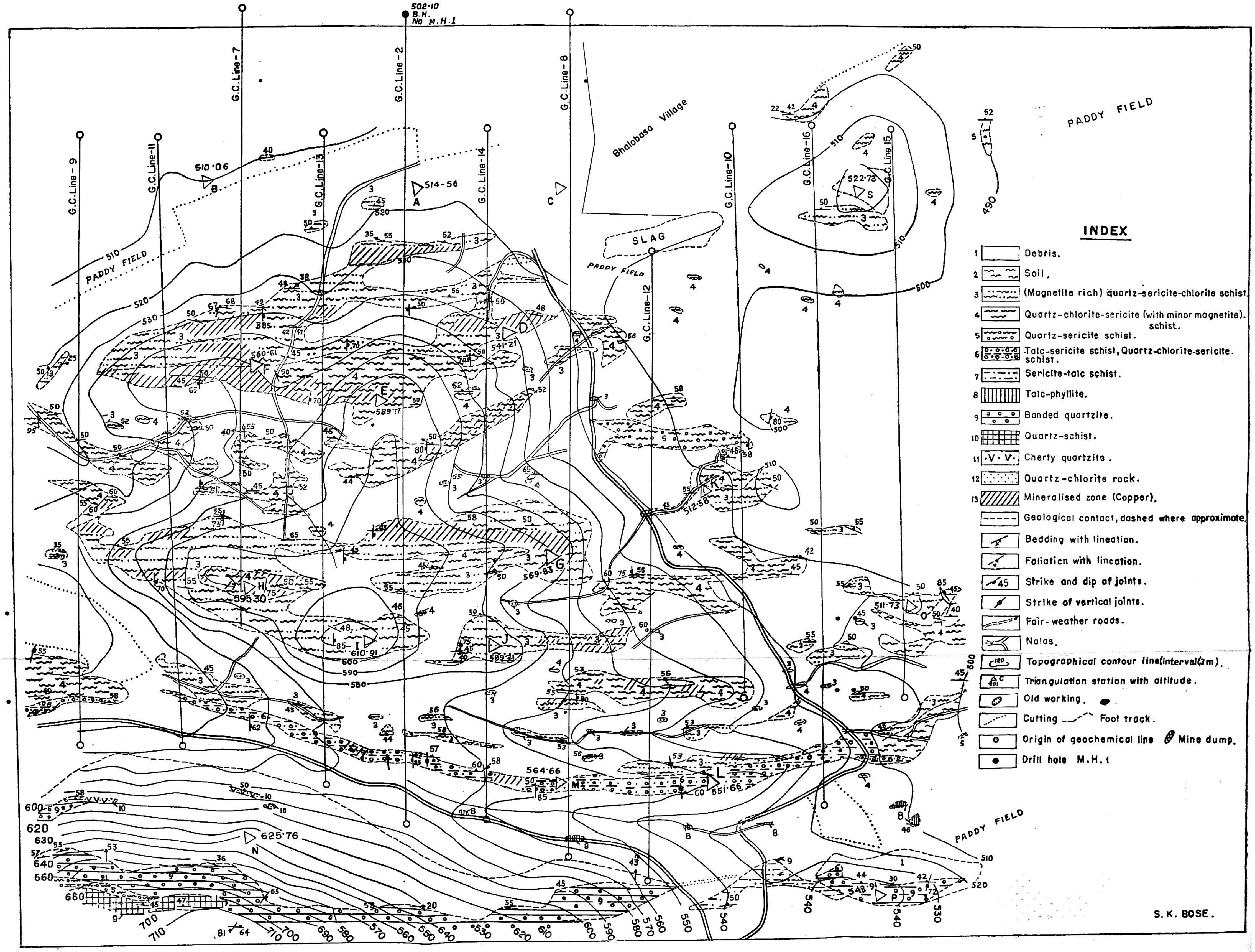


PLATE 17

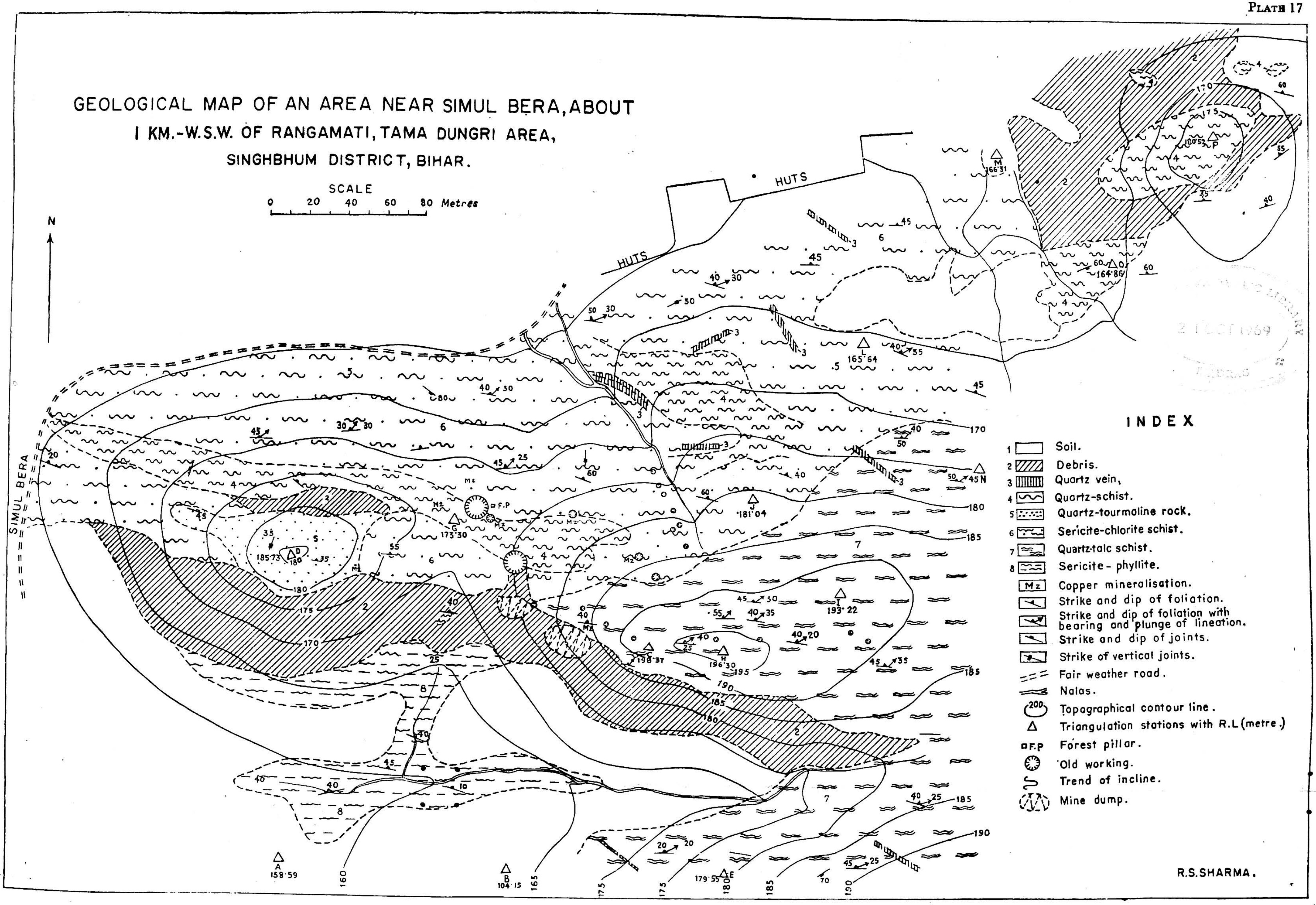
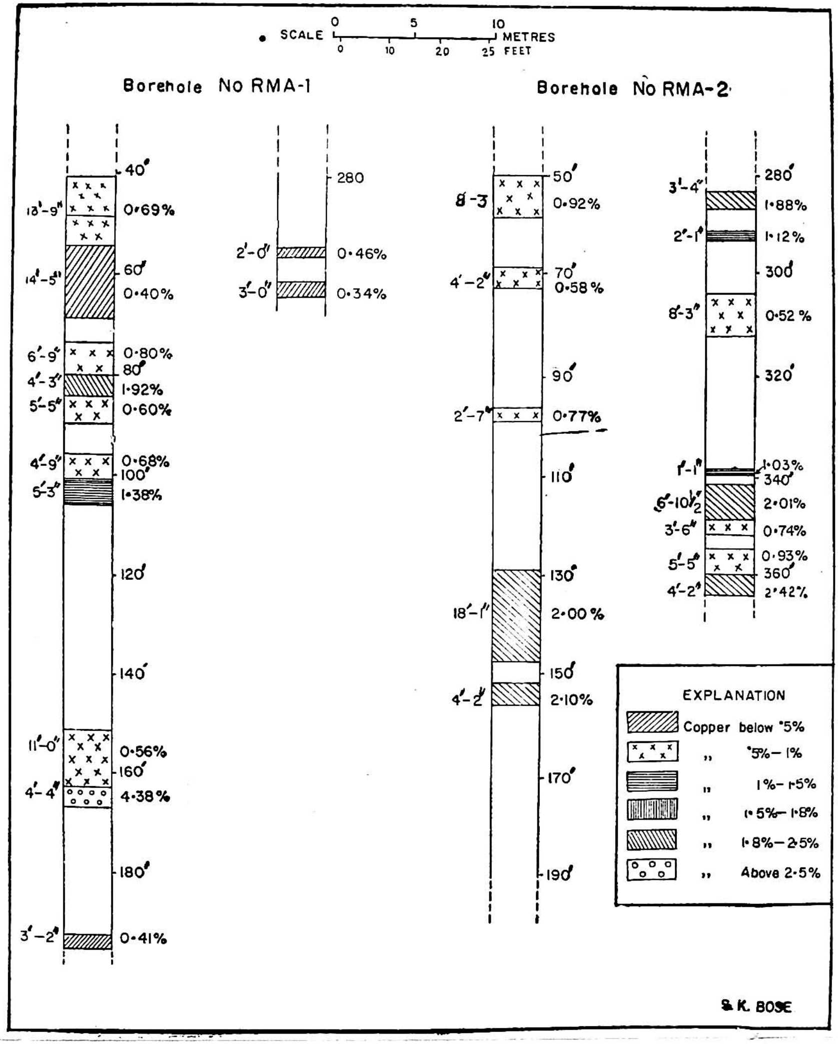

GEOLOGICAL MAP OF AN AREA NEAR SIMUL BERA, ABOUT
1 KM.-W.S.W. OF RANGAMATI, TAMA DUNGRI AREA,
SINGHBHUM DISTRICT, BIHAR.
SCALE
0 20 40 60 80 Metres
N
HUTS
HUTS
SIMUL BERA
INDEX
1 Soil.
2 Debris.
3 Quartz vein.
4 Quartz-schist.
5 Quartz-tourmaline rock.
6 Sericite-chlorite schist.
7 Quartz-talc schist.
8 Sericite-phyllite.
Mz Copper mineralisation.
Strike and dip of foliation.
Strike and dip of foliation with bearing and plunge of lineation.
Strike and dip of joints.
Strike of vertical joints.
Fair weather road.
Nalas.
Topographical contour line.
Triangulation stations with R.L (metre.)
F.P Forest pillar.
Old working.
Trend of incline.
Mine dump.
R.S.SHARMA.

PLATE 18

BOREHOLE SECTIONS SHOWING THE MINERALISED ZONES WITH THE COPPER VALUES

(ROAM-SIDHESWAR BLOCK, SINGHBHUM DIST., BIHAR)



SULPHIDE MINERALISATION IN THE SURDA-BADIA SECTION OF THE SINGHBHUM COPPER BELT, BIHAR

BY

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Geological Survey of India.

(With plates 19-23)

ABSTRACT

From studies of sections in selected levels in Surda, Patharghara, Mosaboni and Badia mines, Singhbhum copper belt, Bihar, it is concluded that the sulphide mineralisation has been controlled predominantly by a set of gently dipping slip planes (S_1) and to a minor extent by the steeper cleavages (S), giving rise to the braided ores. These grade into massive ores in zones of relatively intense shearing. Chalcopyrite and pyrrhotite form both the types, but pyrrhotite is more common in the massive ores.

Polished sections from parts of the above mines show that the sulphide ores consist essentially of chalcopyrite, pyrrhotite and pyrite and there is not much significant variation in the mineralogy with depth. Pyrrhotite and pentlandite are, however, locally concentrated. Octahedral crystals of pyrite are common suggestive of moderately high temperature of deposition. Pyrite is early and is pseudomorphically replaced by chalcopyrite in some ores from the Surda mines. Pyrrhotite and pentlandite are later and chalcopyrite last. Thus the paragenesis of the sulphide minerals postulated by Dunn, holds good for the deeper levels in the Mosaboni mines, and also for Badia and Surda,

INTRODUCTION

Dunn (1934, 1937) recognised that the sulphide mineralisation in the Singhbhum copper belt has taken place in a zone of overthrust in which older rocks of the Iron-Ore series of the north have ridden over the younger rocks of the Dhanjori group to the south. The zone of overthrust is intensely sheared and is characterised by an anastomosing system of shear lines (Dunn, 1937). He also suggested the possibility of using certain branching shear lines as clues for tracing the mineralised channels.

In recent years, several officers of the Geological Survey of India have mapped in detail the Singhbhum copper belt ; geochemical and geophysical surveys have also been carried out. Between 1955 and 1959, parts of the belt between Badia (22°29′ : 86°28′) and Bhatin (22°40′ : 86°20′) and Mosaboni (22°31′ : 86°28′) and Machbhandar (22°26′ : 86°33′) were mapped in detail by Roy Chowdhury and party (1955-56, 1956-57), Bose and party (1958-59), respectively. Wakhaloo (1959) mapped ore shoots in the north bottom section of the Mosaboni mines in levels 18, 19 and 20 in 1957. He attributed ore localisation to certain shear planes trending between N.W.—S.E. and N. 20° W.—S.20°E., indicated as foliation dips of 40°—66° easterly. According to Narayanaswami (1959), the mineralisation has taken place along shear fractures related to cross folds of *en echelon* pattern. From a study of cross-cut sections in levels 18 and 20 in the Mosaboni mines, Deb and Sarkar (1960), concluded that the mineralisation has taken place in a zone of maximum fracturing and tensional dilation which is also a zone of sericitisation

Banerjee (1961) studied a part of the shear zone south of Tatanagar and found that the copper sulphide veins have been emplaced along the axes of a minor set of cross folds.

Though it has been well recognised for long that sulphide mineralisation has taken place in shear planes or shear fractures no details are available on the nature of the structural elements that control the mineralisation, and how they control formation of small or large ore bodies. The present paper deals with (1) such structural features which have localised the sulphides and have given rise to different types of ore, and (2) the mineralogy and paragenesis of the sulphides. The study was confined to critical sections in the Badia, Mosaboni and Surda mines and was aided by mapping of parts of levels 19, 20 and 21 of the Mosaboni mines and the levels 1 and 2 of the Surda mines on the scale 1 cm. = 6 m. and preparation of large scale (1 cm. = 1 m.) sketch maps of parts thereof. A short note on the subject has been presented in the Indian Minerals (Sen Gupta *et al*).

STRUCTURAL CONTROL

The Country Rock

In the mines studied mineralisation has taken place in relatively narrow (5 m. at the maximum) zones, which are parallel to sub-parallel

o one another. In Mosaboni and Badia, mineralisation has taken place in such zones cutting the massive soda-granite (Pl. 19), characterised by a well foliated dark green chlorite rock. The chlorite-schists occur as bands and lenses within the granite. Sulphide veins and stringers (commonly 1-10 mm. thick) occur in the schists only; the veins and stringers of sulphide do not extend into the massive parts of the granite wall, against which they terminate abruptly. In the area studied, there are very few schist bands in the granite, free from mineralisation; the close association of the chlorite-schist and the ore also suggests a genetic relationship of the sulphide-ore with the schist.

Types of Ore

Two types of ore can be distinguished in the mines (Das *et al*, 1961) *viz.*, 'Braided' and 'Massive.'

Braided type :—This is economically the most important type of ore. It consists of numerous thin (commonly 1-10 mm. thick) sub-parallel stringers which occur at an angle to the cleavage or schistosity, which they follow only in part. These in section give a braided pattern. Three dimensionally these would appear like rhomboids, enveloped by sulphide stringers at the solid angles. A characteristic feature of these ore bearing schists is that the cleavage becomes parallel to the vein at either end thus becoming sigmoid in appearance. Disseminations of sulphide within the enclosed rhomboid of schist are minor. The strong impression that the ore has filled opened out fractures which have a regular pattern, is inescapable on a study of the lodes. This pattern is conspicuous in all the mines studied.

Massive type :—The second type is the massive or solid ore (Pl. 20). This consists almost entirely of sulphides with numerous discrete, ubiquitous inclusions of chlorite schist, vein quartz, and in many cases, as in the massive ore bands near 701 m.—north drive, level 18, along 563 m.—north winze, level 19, and 624 m.—north drive, level 21, of Mosaboni mines and rhomboid blocks of granite which appear like pebbles in section. Both laterally, and on the sides, the massive ore grades into the braided ore and appears to form the core within an individual mineralised shear zone. These features, coupled with the ubiquitous nature of the inclusion of schist and the rhomboid granite, suggest that these are not veins of ore filling tension fractures as a solid dyke. They appear to be zones of intense shearing which have been thoroughly impregnated with ore solutions.

In the Surda mines (22°34′ : 86°26′) the massive ore veins have similar cross cut relation with schistosity and in many places enclose rhomboids of schist as do the smaller veins and stringers. Along south-drive (south of 20 S survey station), level 2, a massive ore band runs parallel to the slip-plane trend of W.N.W.—E.S.E. to N.W.—S.E. for more than 20 m. where the cleavage trend is N.W.—S.E. to almost north-south in the host chlorite-schist. Sulphides also occur as irregular fracture fillings in quartz veins, but these are of minor importance.

Structural features

From the foregoing observations it is clear that mineralisation within the shear zone has a characteristic and regular pattern. The veins and stringers are mainly at an angle to the cleavage or schistosity (S) (Pl. 20). The cleavage planes are very closely spaced, and are now recognisable by the parallel flakes of mainly chlorite and subordinate biotite. In places, similar parallel planes can be recognised in sheared granite also, in which chlorite and biotite have crystallised. The cleavage is cut at an angle by a more widely spaced and gently dipping set of fracture planes (S_1) which is mainly filled by the ores. These are of the nature of shear fractures along which there has been movement as is indicated by the bending of the chlorite flakes into a position parallel to the veins. The absence of crushing or deformation of the sulphide veins filling the fractures indicates that movement along the fracture planes took place before the deposition of the sulphides.

The cleavage (S), in general, trends N.W.-S.E. to north-south with an easterly dip varying from 40° to 60°. The slip planes (S_1) have a general trend W.N.W.-E.S.E. to N.W.-S.E. with easterly dip between 8° to 22° (in North-bottom section, Mosaboni mines). The S and S_1 planes are broadly related ; the cleavage always dips at a steeper angle than the slip plane, and where the strike of the cleavage changes, the slip plane strike also changes correspondingly. In the latter case the trend of an ore shoot following the slip plane also changes, which is clear near 609 m.—North-drive, level 20, Mosaboni mines. Here the ore-shoot changes its trend from W.N.W.-E.S.E. to almost north-south when the trend of slip plane changes from W.N.W.-E.S.E. to N.N.W. -S.S.E. Secondly, the cleavage and slip planes dip, in general, at gentler angles at Mosaboni mines than at Surda, while the dip of the mineralised zones is also gentler at Mosaboni than at Surda.

Measured in a transverse section, the dip of an ore band is steeper than the dip of the slip planes (S_1) and gentler than that of the cleavage (S) in the host rock ; and the exact amount is usually nearer to the amount of dip of the slip planes. Locally, massive bands have the same dip as that of the slip plane, in the host chlorite-schist.

CONCLUSION

The present studies limited to sections in the Surda-Badia region in the southren part of the Singhbhum copper belt, indicate that there is a definite, regular pattern in the structural control that localises the thin stringers as well as the lode as a whole. The sulphide mineralisation is largely controlled by the slip planes (S_1) rather than the cleavage (S) in both dip and strike and has taken place mainly where S_1 planes have been well developed.

TYPES OF ORE AND PARAGENESIS

Two types of ore *viz.* braided and massive, have been distinguished from the nature of the constituent veins. Both braided and massive types are composed of stringers and veins of sulphides, a few millimetres to about a centimetre across, in a close network. In zones of rich mineralisation the constituent veins are thicker and form a solid vein, in places as thick as a metre, with very little of gangue minerals. All gradations between lean braided ore with a few stringers, to solid veins can be seen in the mines.

Mineral composition of the different types of ore

Among the major sulphide minerals, chalcopyrite characteristically forms braided ores, but is also known in massive and solid veins, Pyrrhotite forms one or more sub-parallel bands, each about 10 cm. thick, in the core of massive bands, running parallel to them. Away from the solid pyrrhotite-rich bands the percentage of pyrrhotite gradually falls but continues for the whole of the mineralised portion. The pyrrhotite veins have the same pattern as that of chalcopyrite veins, whether in massive or braided ore, but in braided ore, pyrrhotite is in general less in amount. Pyrite is common as distinct crystals embedded within stringers of chalcopyrite and pyrrhotite, but locally is known in solid slip-plane fillings also. Along South-drive, level—1, Surda mines, pyrite crystals are, in places, arranged in strings which form a

crude net work. Rarely (in levels 1 and 2, Surda mines), pyrite occurs as segregations of crystals, within massive chalcopyrite bands, in which pyrite has been partly replaced by chalcopyrite.

Field relation of massive and braided ore

Braided type of ore is very common. In areas of richer mineralisation both massive and solid ores have been formed. Within the thickness of a mineralised zone, the massive ore occupies the core, and passes laterally and across into braided ore. When mineralisation is comparatively poor, ores occur in lean braided type and massive ores are absent. The massive and solid ore bands have cross-cut relationship with cleavage or schistosity (S).

As the constituent veins in massive ore, following S_1 planes, are thicker and more closely spaced than in other types, it appears that the massive ores represent more opened out portions which were the main loci for penetration of ore solutions. As one proceeds away from the core of a shear zone, the slip planes become more and more ill defined and ultimately die out against massive granite, thus accounting for the gradual fall in mineralisation and a passage from massive to braided and then to barren country rock.

Localisation of pyrrhotite and Nickel-sulphides

In the different mineralised sections of the mines, chalcopyrite is found to be very common. Pyrite is also found but barring a few local concentrations, it is scanty in proportion. Pyrrhotite, on the other hand, is high in certain portions of the mines, especially in the North-bottom section of the Mosaboni mines. Outside such portions, pyrrhotite is present but only in small proportions. The North-bottom section is one of the richly mineralised sectors of the mine, where massive ore bands are common. These bands are invariably rich in pyrrhotite and contain considerable amount of pentlandite. Enrichment of pyrrhotite has also been noted in parts of the North-Badia section.

MINERALOGY

The major sulphide minerals constituting the ores are chalcopyrite, pyrrhotite and pyrite ; pentlandite is common in ores from

the North-bottom section of the Mosaboni mines and violarite is rarely present in some pentlandite bearing specimens. Samples of massive and braided ores, and one with minor amount of disseminated sulphides were analysed by X-ray by B. B. Mukherjee of the Geological Survey of India and the presence of the major minerals were confirmed. The analysis gave the following results :

Types of Ore	*Location*	*Minerals identified*
1. Massive Ore P.R. No. 12876 (1)	About 335m. North drive, Level—16, Mosaboni mines.	Chalcopyrite and pyrite—major ; quartz--minor ; millerite—doubtful.
2. Massive Ore P.R. No 12876 (2)	About 671m. North drive, Level—18, Mosaboni mines.	Chalcopyrite and pyrrhotite—major ; quartz—minor.
3. Massive Ore P.R. No. 13020	Near 514m. North drive, Level—19, Mosaboni mines.	Chalcopyrite—major ; pyrrhotite and pentlandite—minor ; quartz—minor.
4. Braided Ore	Near 518m. North drive, Level—19, Mosaboni mines.	Chalcopyrite—major ; pyrrhotite—minor ; quartz—minor.
5. Braided Ore P.R. No. 13021	Near 514m. North drive, Level—19, Mosaboni mines.	Chalcopyrite—major ; pentlandite and malachite—good amount ; quartz—minor.
6. Disseminated Ore, P. R. No. 12876 (5)	Near the intersection of cross cut and South-drive, Level—19 Mosaboni mines.	Chalcopyrite—major ; Quartz—minor.

MINERAGRAPHY

The mineragraphy of the ores from deeper levels of the Mosaboni mines is similar to that of ores from upper levels, as described by Dunn (1934, 1937). Texturally, the ores from Badia and Surda mines are similar to those from Mosaboni. The mineral constituents in all these ores are the same, with local variation in relative proportion.

Chalcopyrite : Chalcopyrite predominates over all the other sulphides in all types of ores. It occurs in xenomorphic grains 0·09 mm.

to 0·6 mm. across in massive ore, the mineral occurs in grains finer than in braided ore. Under the microscope the mineral appears in wide areas, in many places extending into interstices of pyrrhotite grains and fractures in pyrite and quartz.

Pyrrhotite : Pyrrhotite is the next dominant sulphide, especially in the massive ores, and locally may dominate over other sulphides. It occurs in extremely irregular patches composed of xenomorphic grains, 0·05 mm. to 0·1 mm. across ; distinct grains enclosed in chalcopyrite are common. In massive ores, pyrrhotite and chalcopyrite form a close network enclosing numerous elongated and rounded inclusions of quartz. Rarely, the mineral extends into crystals of pyrite along fractures, and may be replaced by chalcopyrite filling the same fractures later.

Pyrite : Pyrite characteristically occurs in discrete grains within chalcopyrite or pyrrhotite. In richly mineralised portions and in solid sulphide veins, it commonly occurs as automorphic octahedral crystals, 1 to 5 mm. across. Rarely pyrite may form solid microveins about a centimetre thick. In some massive ores a network of small and thin veins of pyrite similar to those of chalcopyrite have been noted. Pyrite grains usually have extremely irregular boundaries and are, in many places, cut by microveins of chalcopyrite and rarely of pyrrhotite.

In ores from Levels 1 and 2, Surda mines, crystals of pyrite have been pseudomorphically replaced by chalcopyrite. Most of the crystals are automorphic with characteristic four-sided and six-sided outlines. Replacement commenced along interconnected microveins which are always confined within the limit of individual crystals (Pl. 21, figs. 1 and 2). Near the margin, these veins, in many places, join broad areas of chalcopyrite, which do not continue into the quartz-chlorite groundmass, but are confined within limits of the host pyrite crystal, preserving the original crystal outline. Unreplaced relicts of pyrite in chalcopyrite are common. In some specimens pyrite shows traces of (111) and (100) cleavage, some of which have been followed by microveins of chalcopyrite. Pyrrhotite, where present, bears the same relationship with pyrite. When the replacement is more advanced, the whole of a pyrite crystal has been replaced by chalcopyrite, preserving the original form of pyrite (Pl. 22, figs. 1 and 2).

In some specimens of chlorite-schist automorphic crystals of pyrite occur transecting schistosity, which is not deflected by the crystal.

Pentlandite : It is a common associate of pyrrhotite in ores from the North-bottom section of the Mosaboni mines, and in some specimens it is abundant. It occurs (1) in xenomorphic granular aggregates with pyrrhotite and (2) as thin curving microseams rimming pyrrhotite grains, presenting a typical rim texture.

Violarite : Violarite is comparatively rare and occurs only in association with pentlandite, replacing the latter. The replacement in some sections is guided by cleavage planes or cracks (Pl. 23, fig. 2) in pentlandite ; elsewhere it has advanced with equal facility in all directions (Pl. 23, fig. 1). The replacement is pseudomorphic and as such violarite has preserved the cracks in pentlandite. In places violarite occurs as a narrow rim surrounding an unreplaced core of pentlandite.

PARAGENESIS

The paragenesis noted by Dunn (1934, 1937) from study of samples collected from the upper levels of the Mosaboni mines, holds good in general, in ores from greater depth, and in those from Badia and Surda Mines. Chalcopyrite, pseudomorphic after octahedral pyrite, has been noted (for the first time here) in ores from Surda mines, the presence of which provides undoubted evidence of pyrite having been replaced by chalcopyrite. Hence pyrite was deposited earlier than chalcopyrite as was postulated by Dunn. Abundance of octahedral habit in pyrite crystals suggests (Sunagawa, 1957,) that (1) the pyrite has been formed by slow cooling from a moderately high temperature, and (2) there was sufficient supply of the ore solutions depositing pyrite. The conditions are in keeping with the idea of an earlier deposition of pyite. Pyrrhotite has been noted to follow fractures in pyrite crystals in ores from Badia and Surda and must be later than pyrite. Seam like bodies of pentlandite have presumably been exsolved from pyrrhotite and hence must have separated along with pyrrhotite. Violarite replaces pentlandite along cracks and cleavage planes and is

younger than pentlandite. Chalcopyrite replaces pyrite and pyrrhotite and is the youngest. The time relationship between violarite and chalcopyrite is not clear, as violarite replaces pentlandite pseudomorphically, because of which the textural characters of pentlandite have been inherited by violarite. The relation between violarite and chalcopyrite, as it is seen now, is only what chalcopyrite had with pentlandite before the latter was replaced by violarite.

ACKNOWLEDGEMENTS

The authors wish to thank the General Manager and the Mines Superintendent, of the Indian Copper Corporation, and express their deep sense of indebtedness to late Shri Sahoo for the keen interest shown and for providing all facilities to carry out this study.

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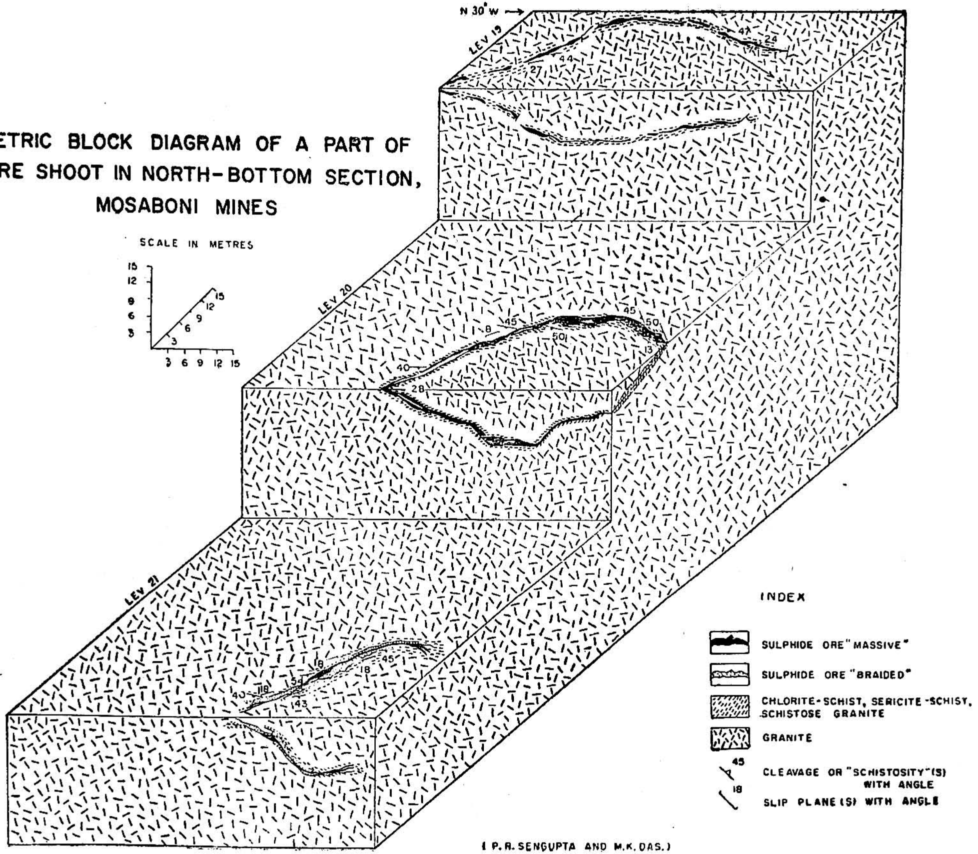
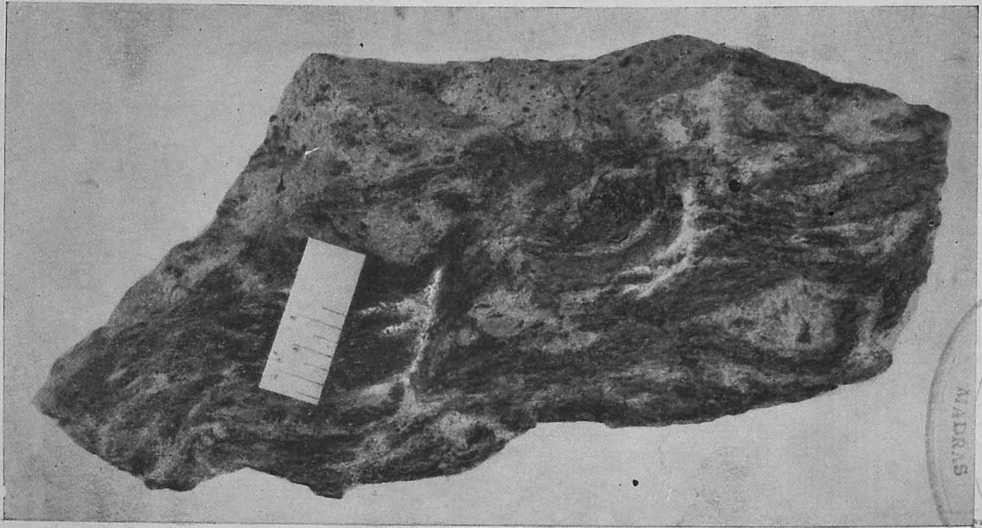


ISOMETRIC BLOCK DIAGRAM OF A PART OF AN ORE SHOOT IN NORTH-BOTTOM SECTION, MOSABONI MINES

(P. R. SENGUPTA AND M. K. DAS.)

MO
MO
MO
A

PLATE 20



Photograph of a hand-specimen of chlorite "schist" showing alignment of ore stringers. Long continuous lines show trace of cleavage (S). Four sub-parallel stringers, running almost north-south in the photograph, fill slip-planes (S_1) and throw small branches along cleavage. O-ore, mainly chalcopyrite, MO- Massive ore, A- apatite,

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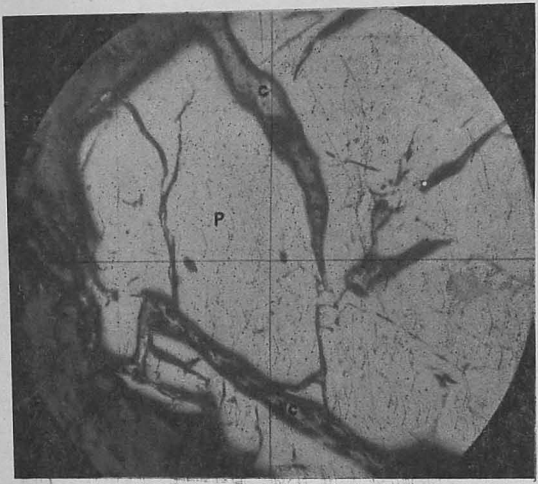

Fig. 1. Pyrite(p) (pale grey, higher relief) with automorphic outline, replaced by chalcopyrite(c) along cracks. × 30.

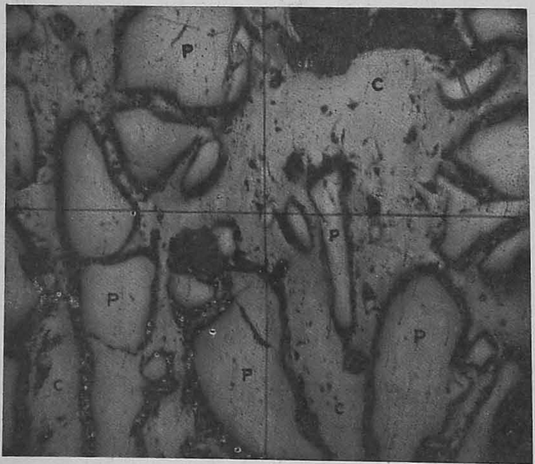

Fig. 2. Replacement more advanced : relict islands of pyrite(p) (higher relief, pale grey) enclosed in chalcopyrite(c) (slightly darker grey) area. × 45.

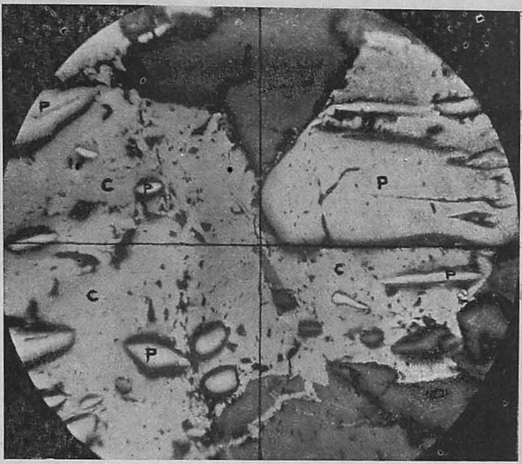

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Fig. 1. Replacement almost complete: only small relict islands of pyrite(p)(higher relief, white) enclosed in chalcopyrite(c) (pale grey) areas. Note crystal outline in chalcopyrite inherited from pyrite. × 30.

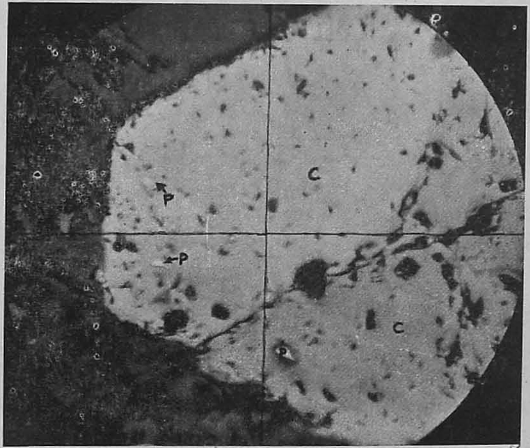

Fig. 2. Replacement complete : chalcopyrite(c)(pale grey) with crystal outline characteristic of pyrite ; only one or two small islands of pyrite(p)(higher relief, white) can be seen. × 30.

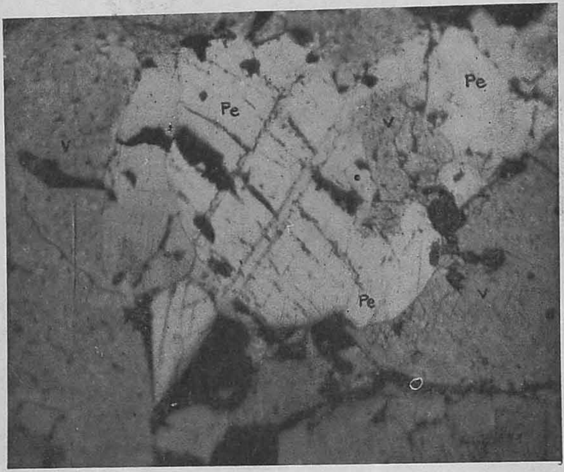

Fig. 1. Pentlandite(p)(greyish white to white) pseudomorphically replaced by violarite(v)(pale to dark grey). × 200.

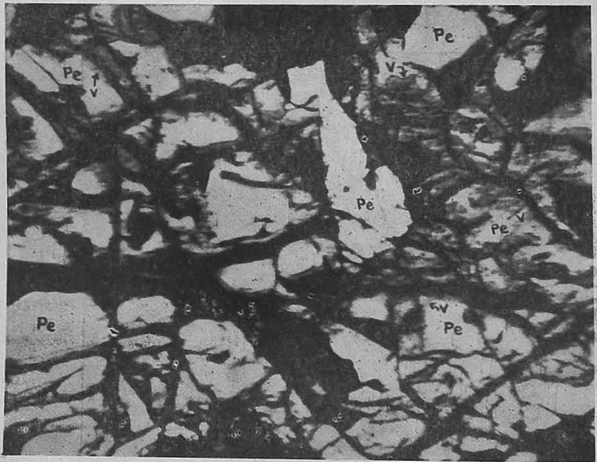

Fig. 2. Pentlandite(p_e)(white) replaced by violarite(v)(dark grey) along cracks. × 150.

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A NOTE ON THE OLD COPPER WORKINGS OF AMBA MATA NEAR ABU ROAD STATION GUJARAT

BY

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ABSTRACT

The paper draws attention to the old copper workings which exist near Amba Mata (Ambaji) town, famous for its *Durga* temple and a Jain temple, both of which have been built on old slag heaps. There are several old pits on the summit of a low ridge near Amba Mata, and some of them look like collapsed shafts. Detailed geological and geophysical prospecting of the area is suggested which may lead to the location of a copper deposit, possibly associated with lead.

INTRODUCTION

Amba Mata (24°20′ : 72°53′), popularly known as Ambaji, is situated at a distance of about 18 km. south-east of the Abu Road station and about 45 km. north-east of the Palanpur station, Western Railway. The town is famous for its ancient temple of *Durga* and a big Jain temple at Kumbaria in its neighbourhood to the south. The area around these two temples is strewn with old slag, and the temples themselves have been built on slag heaps.

The existence of the old workings near Amba Mata was first brought to our notice by late Prof. K K. Mathur who along with Dr. H. L. Chhibber, took two of his postgraduate students (V. S. Dubey and the author) in 1923 to Danta State (then in Mahikantha Agency, North Gujarat) for training in field work. Mathur and Chhibber (1925) contributed a paper on the geology and mineral resources of the northern part of Danta State, and Chhibber (1925) a paper on the old copper slags from Amba Mata and Kumbaria in Danta State. Later, Chhibber (1927) published a paper on the metamorphic rocks and minerals of the copper deposit near Amba Mata.

The geological mapping of the remaining portion of the Danta State was completed by the author and a note on the geology of Danta State was published in 1931. Danta State was then surveyed by the Geological Survey of India and the paper on the geology of Palanpur, Danta and part of Idar States was published by Dr. A.-M. Heron and late Dr. P. K. Ghosh (1938)

OLD WORKINGS

The old copper workings of Amba Mata occur on the top of a ridge which runs north-west from the town, parallel to the road to Abu Road railway station. The ridge is less than 90 m. above the general level of the plain, and the workings extend for about 1.5 km. along the summit of the ridge. The country rocks, according to Heron and Ghosh (1938), are talc-schist, mica-schist and shattered quartzite traversed by numerous quartz veins, and are regarded by these authors to belong to the lower division of the Ajabgarh series. According to Chhibber, chlorite-schist, tremolite-schist, anthophyllite-schist and actinolite rock (derived from older schistose quartz-porphyry and diorite) are the country rocks and quartz veins, tourmaline-pegmatites and schorl rock are also seen in the area. He regards these rocks as Aravallis and all of igneous origin. The present author considers the characteristic quartz-porphyry of this area as post-Aravalli and pre-Delhi in age, and according to him, a gradation can be easily traced in this rock from a white quartz-porphyry (resembling quartzite in hand specimen) through a schistose quartz-porphyry to an almost sericite or muscovite-biotite schist. These rocks are characterised by light grey colour and constant presence of phenocrysts of blue quartz. Heron and Ghosh (1938) cosldered these rocks as arkose with the possibility that they might be porphyries. These rocks as well as the marble and crystalline limestone occurring to the east of the area, are intruded by epidiorite This area is flanked on the west and south-west by a vast intrusion of Erinpura granite and on the south by post-Aravalli but pre-Delhi granite-gneiss (which Heron and Ghosh regard as variant of Erinpura granite). It is believed that the source of the mineralising solutions was the Erinpura granite as is the case with other similar deposits of Rajasthan.

The fragments of the above described rocks are spotted with encrustations of either malachite or chrysocolla, which also occur as films in joints and cracks. There are several small pits along the ridge and some of them appear to be the mouths of old shafts which have since collapsed. Many of these pits show abundance of limonite. For example, one of the pits, locally named 'Ramji Khan' (yellow ochre quarry), contains abundant yellow ochre, associated with spongy quartz and highly altered chlorite-schist, which has been localey used as a paint or dye.

No primary ores of copper have been found in the old workings and only the oxidised zone of the deposit is seen at present. Large lumps of galena had once been found in a cutting on the road to Abu Road station, about two miles from Amba Mata, and the author had observed occasional grains of galena in the marble rock cropping out east of the area and intruded by epidiorite in which small grains of pyrite and chalcopyrite are sometimes observed. It is, therefore, possible that the slags of the Amba Mata area may not all be the products of copper smelting, but may partly be from smelting of lead which must have been more in demand for manufacture of lead shots for guns

The area is worth prospecting geologically. Methods of geophysical prospecting (probably magnetic and self-potential and other electrical methods) may also be employed to locate the ore-body.

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THE NEWLY LOCATED SILICIFIED AND GOSSANISED BELT NEAR MUNDATIKRA, BASTAR DISTRICT, MADHYA PRADESH

BY

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(With Plates 24-28)

ABSTRACT

A new silicified and gossanised belt was located north of Mundatikra village (19° 28′ : 81° 19′;65 E) in Narainpur *tehsil*, Bastar district, Madhya pradesh, in early 1959. The belt is 150 m. wide in the central part and extends over a length of four kilometres. Sulphide mineralisation, indicated mainly by several large patches of gossan, distributed along a fault zone, is confined to shales belonging to the Bailadila series, which is equivalent to the Iron-ore series of Singhbhum in Bihar. The study of these outcrops (gossan), with regard to the colour, texture etc., and the presence of residual grains of sulphide minerals suggests the presence of original sulphides of copper along with other sulphides. Exploratory drilling operation has proved a number of horizons of sulphide mineralisation, in some of which copper mineralisation is indicated by the presence of chalcopyrite and covellite.

Geochemical analysis of soil samples indicate significant association of copper, nickel and cobalt. The sub-surface geochemical values of copper show a sharp rise With depth even in the oxidised zone to which drilling has been confined. (Rise in sub-surface values of cobalt and nickel has also been noticed). For assessing the economic possibilities of the area deep drilling so as to reach the primary zone of zones of mineralisation is necessary.

INTRODUCTION

Preliminary investigation supplimented by geochemical sampling was carried out in May 1959 in the silicified and gossanised belt near Mundatikra (19°28′ : 81°19′), Bastar district, Madhya

Pradesh, first located early in 1959. Detailed investigation of the area by means of drilling was conducted during the field seasons 1959 to 1962*

The work comprised mainly, (1) preparation of large scale (1 : 1,200) geological map of the area, (2) mapping and geochemical sampling in the adjacent terrain to trace the extension of the belt, and (3) drilling.

The area is provided with only rudimentary communication facilities. The village Chota Dongar (19°27′ : 81°20′) is connected with Narainpur (19°43′ : 81°15′), the *tehsil* headquarters, by a 42 km. long fair weather road. The nearest railheads are at Rajnadgaon and Rajahra *pahar* on the South Eastern Railway, which are about 176 and 128 km. respectively by road. The village Mundatikra is only 500 m. north of Chota Dongar.

The region is locally known as 'Abhuj mar' (unknown hills) and is a plateau with undulating topography and numerous small knolls rising 900 m. above m.s.l.

These knolls mainly comprise banded hematite-quartzite running more or less north-south and extend intermittently from Bailadila in the south to Dalli Rajahra in the north. These form the repositories of iron-ore, which occurs in small or big patches throughout the 250 km. stretch, with great concentrations at Bailadila, Rowghat, Ari Dongri and Dalli Rajahra.

During the course of reconnoitory survey early in 1959 an east-west dislocation was observed north of Mundatikra village. This fault zone is made conspicuous by a silicified horizon with intermittent patches of gossan showing characters of sulphide mineralisation. This zone extends from Kumhari *dongri* (hill) in the west to Bargaon *dongri* to the east over a length of about four kilometre.

GEOLOGY

The sequence of rock types in the area is as follows :—

ARCHAEAN (Bailadila series)	Granite gneiss Banded hematite-quartzite Ferruginous shale Quartz-sericite schist

* Additional data obtained till 1963 have been included in this paper.

The Bailadila series consists of ferruginous shale and banded hematite-quartzite. The thickness of the latter varies from 9 to 60 m. The granite gneiss comprises mainly quartz, felspar (mainly orthoclase), biotite, magnetite, apatite and chlorite. The felspars are highly kaolinised.

The rocks of the Bailadila series are intricately folded. A fault of great magnitude was noted in the Mundatikra area. This has a general N.85°W.—S.85°E. trend and could be traced for a strike length of about four kilometres. There has also been a considerable amount of shearing all along the fault zone. The intensity of disturbance is greatly pronounced along the central portion of the zone.

The fault zone, which is 150 m. wide in the central part, is characterised by the presence of silicified and brecciated rocks. A study of the silicified rock has shown that the rock from which it has been derived, was mainly shale and to some extent quartz-sericite schist. The brecciated rock consists of angular fragments of banded hematite-quartzite, cemented by a siliceous and ferruginous matrix. The silicified masses occur in a prominent *en echelon* pattern towards the middle of the fault zone. Being strongly resistive to erosion, these silicified bodies stand up prominently above the general level of the country.

The silicified bodies are highly fractured and jointed, both radial and oblique type of fractures being present. These appear to be of two ages: (1) pre-sulphide mineralisation and (2) post-sulphide mineralisation. The first set of fractures is mineralised while those of the second set is barren.

The contour diagram (Pl. 24) of the joints, based on 200 observations in the silicified rocks shows that (1) There is a high percentage of vertically (or steeply) dipping conjugate system of joints trending N.70°W —S 70°E. and N.70°E.—S.70°W. (2) There is another fair number of vertically (or steeply) dipping conjugate system of joints trending approximately north-east and south-west and joints with a strike varying from north-south to N.20°W.—S.20°E. (3) There are also some joints which are moderately dipping in a north to north-east direction.

Both the flanks of the hills are covered by a thick mantle of talus, formed of silicified rocks, gossan and banded hematite-quartzite. Close to the contacts of the flanks with the general ground level on both sides of the hills is granite gneiss, though obscured from view by talus.

MINERALISATION

The important mineralised horizons occupy the central portion of the fault zone from 90 m. east to 1,050 m. west of the '0' station. The mineralisation is controlled by :

(1) fractures, both radial and oblique, in the silicified rock,

(2) pockets of shale caught in between closely spaced silicified bodies,

(3) contact of the silicified body with shale.

The above fractures have served as the main channelways for sulphide mineralisation. The mineralised rocks, on subsequent oxidation and leaching, have given rise to gossan, seen in intermittent patches in the area. Excellent gossan exposures are invariably associated with closely spaced fractures. Intensive kaolinisation has also been noted in this zone. The sulphide mineralisation is denoted by the different types of limonite boxwork, voids left in the silicified rock and relict sulphides like pyrite and a few grains of pyrite cubes. Secondary minerals like hematite, limonite, malachite and azurite have also been distinguished.

Some worker like Locke (1926) have shown that the presence of indigenous limonite in gossans indicate original association of copper sulphides which have subsequently been leached out. The colour of the limonite in these gossan outcrops, is in general, brown to seal brown and maroon representing different types of indigenous limonite which are described below along with their interpretations (after Locke).

Relief Limonite : Most of the gossans in the cappings is minutely craggy, cavernous and porous indicating the presence of indigenous limonite in the form of relief limonite (Pl. 26, fig. 1). The colour in general is dark, approaching black. Tiny sponges are seen rising above the general surface showing some relief. It is attributed to chalcopyrite or covellite accompanied by pyrite.

Limonite Pitch : Dark to almost black coloured limonite with pitchy lustre, known as limonite pitch, is seen in some of the specimens especially in the lace-work of tiny veinlets and fine limonite box work. This is attributed to bornite and chalcopyrite accompanied by pyrite.

Limonite boxwork :

(a) *Fine cellular boxwork* :—It occurs in indigenous blebs often as mere specks peppered through the matrix but sometimes growing to diameters of about two centimetres. Each bleb consists of a sponge with fine angular cells with walls of paper like thickness. This has been attributed to bornite and chalcopyrite accompanied by pyrite.

(b) *Coarse cellular boxwork* :—It occurs as blebs with diameters varying from one to five centimetres. Each bleb or nodule consists of coarse angular boxwork made up of limonite with thin, wide, rigid walls, one to five millimetres apart. The walls are, in part, continuous in straight lines past several cells, and these lines are repeated in parallel orientation throughout the specimen (Pl. 26, fig. 2). The external colour is dark brown. This reveals former presence of a mixture of chalcopyrite and pyrite.

Botryoidal cavity lining : In some of the samples, the limonite, dark brown to black in colour, is compacted to the walls of the cavity and void and its surface is sub-metallic and minutely nodular or botryoidal. This is the kind of limonite into which relief limonite passes by gradation as the proportion of pyrite to chalcopyrite increases.

Triangular and trapezoidal boxwork : Some of the limonite shows characteristic ochreous orange colour on the walls of the cells, larger triangular cells enclosing the smaller ones with walls up to one millimetre thick and made up of quartz, giving an overall triangular or trapezoidal pattern (Pl. 26, fig. 3). This is attributed to massive bornite.

In some samples triangular veinlets of quartz are seen enclosing the silicified material with minor cells. This indicates the former massive sulphide which has been leached out leaving behind the confused aggregate. The triangular veinlets are likely to be guided by the cleavages or fracture planes in the massive sulphide.

Voids : Cubic voids after pyrite are seen in large numbers in the silicified rocks indicating that large amount of original pyrite has gone in solution during oxidation (Pl. 27, fig. 1).

Geochemical samples :—Soil samples were collected in a grid pattern from both the flanks of the ridge and the hill tops, where possible.

Geochemical analyses of these samples (from depth 0.5 to 0.65 m.) indicate significant increases in the amount of copper, nickel and cobalt in the vicinity of the fault zone against the background average value of copper 50 p.p.m., nickel 50 p.p.m. and cobalt 10 p.p.m. The location of the geochemical sample points and their *analytical results are shown* (Pl. 25). The copper values are high in samples collected from the flanks, close to the zone whereas the nickel and cobalt values are high in sample from the zone, particularly near gossan. This suggests that the gossans represent the zones of sulphide mineralisation.

The sub-surface geochemical values of copper show a definite rise with depth even in the oxidised zone. The increase in the copper values with depth in the mineralised zones established in different boreholes is shown in the tables 1 and 2.

TABLE 1.

Main mineralised horizon.

Borehole number	Drilling length (in metres)	Depth from the surface (in metres)	Copper values %	REMARKS
MT 1	46.02 to 53.93	50	0.005 to 0.0075	Sludge samples analysed. About one and a half times the background value (0.005 %).
MT 1b	106.02 to 113.65	110	0,015 to 0.06	Sludge samples analysed. About three to twelve times the background value.
MT 1a	135. 3	140	—	Drilling stopped just short of the mineralised zone. No proper core or sludge recovered.
MT 1c	175.40 to 184.16	175	0.015 to 0.08	Sludge samples analysed. About three to sixteen times the background value in general.
MT 1d				The drilling operation was discontinued before reaching the zone.

TABLE 2

Subsidiary mineralised horizons

Borehole number	Drilling length (in metres)	Depth from surface (in metres)	Copper values %	REMARKS
MT 1	11·27 to 21.9	18	0·005 to 0·02	Sludge samples analysed. Up to four times the background value (0·005%).
MT 1a	28·65 to 43·18	38	0·06 to 0.25	Sludge samples analysed. Twelve to fifty times the background value.
MT 1b	58·52 to 72·54	70	Up to 0·04	Sludge samples analysed. Up to eight times the background value.
MT 1c	115·43 to 134·91	130	Up to 0·17	Sludge samples chemically analysed for part of the zone. Up to thirtyfour times the backgro nd value.

The rise in the sub-surface value of nickel and cobalt with depth has also been noticed in the boreholes as shown in Table 3 .

TABLE 3

Borehole number	Drilling lengths (in metres)	Depth from surface (in metres)	Nickel/cobalt values %	REMARKS
MT 1b			Nickel	
	117·96 to 132·84	112	0·002 to 0·08	Sludge samples analysed. Four to sixteen times the background value (0·005%).
	140·44 to 143·40	120	0·015 to 0·025	Sludge samples analysed. Three to five times the background value.
	146·26 to 161·20	120	0·025 to 0·08	Sludge samples analysed. Five to sixteen times the background.
			Cobalt	
MT 1b	136·51 to 136·81	115	0·08	Sludge samples analysed. Eighty times the background value (0·001%).
	139·85 to 143·50	120	0·01 to 0·02	Sludge samples analysed. Ten to twenty times the background value.

(All the above analyses are geochemical)

Microchemical tests :—Stains and metallic grains too small to be identified, present in the samples from gossan and silicified rocks have, on microchemical tests, given indications of traces of copper and/or nickel.

Petrological Study:—The examination of polished sections of several samples under reflected light revealed the presence of pyrite, chalcopyrite and eovellite, pyrite being in abundance. Under very high magnification some of the pyrite crystals show minute fractures filled with chalcopyrite-pyrrhotite assemblage. The presence of chalcopyrite and covellite replacing chaleopyrite along the cracks and the grain margins are noted in the samples from the drilling length 49.68 m.—53.03 m. in borehole MT 1 (Pl 27, ig 2). Chalcopyrite enclosed inside pyrite and also along the grain margin is observed in polished sections from the drilling length 137.76 m. - 142.63 m. in borehole MT la (Pl. 27, fig. 3) and drilling length 115.43 m. - 115.62 m. in borehole MT 1c.

The order of paragenesis of these sulphides may thus be noted as : pyrite - pyrrhotite - chalcopyrite - covellite.

DRILLING

To prove the nature and type of mineralisation, drilling was started in January, 1960. Five boreholes were put down, all located on the same cross-section in Kumhari *dongri*, 300 m. west of Dhurwada *nala* (Pl. 25) in order to study the behaviour of mineralisation with depth (Pl. 28).

Borehole No.MT I : It is the first upper hole, 40° from the horizontal towards N.20°E. A total of 107.58 was drilled in this hole. The details of the important zones encountered in this hole are shown in Table 4.

Table—4

Drilling length (in metres)	Length of zone (in metres)	Cu %	Summarised log	Remarks
46.02–49.68	3.66	0.005	Limonite boxwork with little silicification and occasional grains of pyrite. (evidently leached zone).	Main mineralised zone. Sludge samples analysed geochemically.
49.68–53.93	4.25	0.005–0.0075	*Silicified rock with voids and* sparse dissemination of chalcopyrite and covellite replacing chalcopyrite.	

Borehole No.MT 1a : It is the second upper hole, 70° from the horizontal towards N.20°E A total of 148.62 m was drilled in this hole. The details of the important zones met with are shown in Table—5.

Table—5

Drilling length (in metres)	Length of zone (in metres.)	Analytical data			Summarised log	Remarks
		Cu %	Ni %	Co %		
28.65—30.48	1.83	0.1	0.0075	0.008	Silicified rock with relict shale. Many voids and much limonite boxwork.	Sludge samples analysed geochemically.
32.46—34.82	2.36	0.005 to 0.1	0.005	0.02	-do-	-do-
38.71—43.18	4 47	0.06 to 0.15	<0.005 to 0.10	<0.002 to 0.004	Limonite boxwork with little silicified rock and relict shale.	-do-
67.37—68.88	1.61	0.005 to 0.07	<0.001 to 0.006	<0.005	Silicified rock with massive pyrite.	Core analysed geochemically.
135.03—148.62	13.59	<0.005	<0.005	<0 001	Mostly no core and sludge recovery. Silicified rock with chloritic phyllite and sulphide mineralisation.	Sludge analysed geochemically.

Borehole No. MT 1b : This is the middle hole 40° from the horizontal towards N 20°E. A total of 167.88 m. was drilled in this hole. The details of the important zones met with are shown in Table-6 :

Table—6

Drilling length (in metres)	Length of zone (in metres)	Analytical data			Summarised log	Remarks
		Cu %	Ni %	Co %		
48.92—50.32	1.4	0.005	<0.005	<0.001	Sand. No core.	
63.03—64.19	1.16	0.015 to 0.03	<0.005 to 0.005	<0.001 to 0.001	Silicified rock with relict shale and pyrite mineralisation.	Sludge samples analysed geochemically.
65.77—67.45	1.68	0.005	0.01	0.0015	Sand. No core.	
106.22—113.68	7.47	0.015 to 0.06	<0.005 to 0.01	<0.001 to 0.001	Silicified rock with pyrite mineralisation and gossan.	Main zone of mineralisation. Sludge samples analysed geochemically.
148.37—149.93	1.56	0.0125	0.06	0.001	Silicified rock with small voids and pyrite mineralisation.	Sludge samples analysed geochemically.

Borehole No. MT 1c : This is the first lower hole, 45° from the horizontal towards N.20°E. A total of 231·70 m.was drilled in this hole. The details of the important zones met with are shown in Table—7.

Table—7

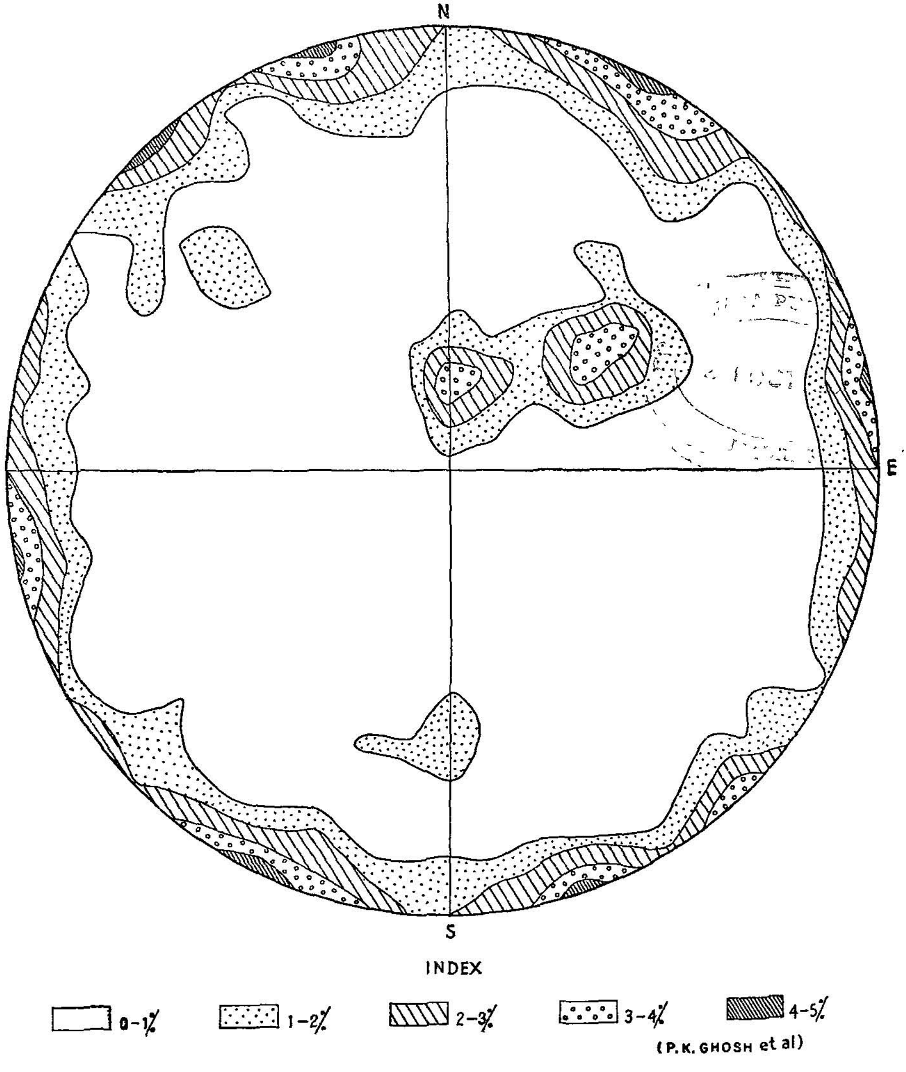
Drilling length (in metres)	Length of zone (in metres)	Analytical Drilling length (in metres)	Cu %	Summarised log	Remarks
115·43—134·94	19·51	128·96—130·55 130·55—133·11 133·11—133·64	0·05 to 0·17	Silicified rock with chlorite and kaolin, and with intermittent pyrite mineralisation and a few disseminated grains of chalcopyrite. No core from 128·96 to 130·55 and 133·11 to 133·64.	Only part of the zone chemically analysed.
156·43—157·33	0·90	—	Trace	Silicified rock, chloritised and kaolinised with pyrite mineralisation and traces of chalcopyrite.	Core chemically analysed.
175·40—183·16	7·76	—	0·015 to 0·08 in general	Silicified rock, chloritised and kaolinised wiih sulphide mineralisation (pyrite and chalcopyrite).	Sludge analysed geochemically.
205·94—211·75	5·81	—	—	Silicified rock, chloritised and kaolinised with minor sulphide mineralisation.	

Borehole No. MT 1d : This is the second lower hole, 55° from the horizontal in the direction N.20°E. A total of 198. 19 m. was drilled in this hole prior to the premature suspension of drilling in view of the approaching rains, before the main mineralised horizon could be reached.

The above data show that there has been abundant oxidation, evidenced by the presence of kaolinisation voids and limonite boxwork. Oxidation and leaching have gone very deep, even below 150 m. from the surface. The boreholes MT 1, MT 1b, MT 1c and MT 1d are

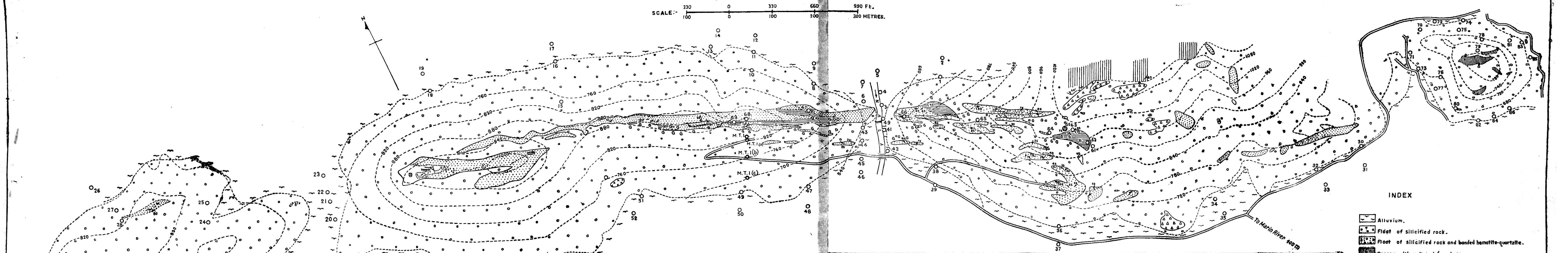
PLATE 24

CONTOUR DIAGRAM OF JOINTS (200) IN THE SILICIFIED AND GOSSANISED BELT, MUNDATIKRA, BASTAR DIST, MADHYA PRADESH.



(P.K. GHOSH et al)

GEOLOGICAL MAP OF THE MUNDATIKRA SILICIFIED AND GOSSANISED BELT, BASTAR DISTRICT, MADHYA PRADESH



GEOCHEMICAL ANALYTICAL DATA

Sl.no. ○	Cu ppm.	Ni ppm.	Co ppm.
1	<50	<50	40
2	50	<50	<10
3	50	50	<10
4	100	50	10
5	100	50	<10
6	100	50	10
7	100	<50	10
8	<50	<50	<10
9	<50	50	10
10	100	50	10
11	150	<50	10
12	100	<50	10
13	100	<50	10
14	100	<50	10
15	100	<50	10
16	100	<50	10
17	100	<50	10
18	<50	50	10
19	100	<50	<10
20	50	75	10
21	<50	50	<10
22	50	<50	<10
23	50	<50	<10
24	50	<50	10
25	<50	50	20
26	<50	<50	10
27	50	<50	<10
28	50	50	15
29	50	<50	<10
30	50	50	10
31	<50	<50	10
32	75	150	10
33	50	<50	10
34	<50	<50	<10
35	<50	<50	<10
36	<50	50	10
37	<50	75	10
38	<50	50	10
39	<50	50	<10
40	<50	<50	10
41	<50	<50	10
42	<50	150	10
43	<50	100	40
44	75	50	<10
45	<50	50	<10
46	<50	50	10
47	50	50	10
48	50	<50	<10
49	<50	<50	<10
50	<50	<50	<10
51	<50	<50	<10
52	50	<50	<10
53	50	<50	<10
54	50	50	<10
55	50	<50	<10
56	50	50	<10
57	50	50	<10
58	50	100	10
59	50	100	10
60	75	50	<10
61	75	<50	15
62	100	75	15
63	<50	75	20
64	<50	150	20
65	50	125	30
66	50	125	30
67	125	100	30
68	75	150	40
69	75	100	20
70	<50	<50	10
71	<50	<50	<10
72	<50	<50	<10
73	50	<50	<10
74	<50	<50	<10
75	<50	<50	<10
76	50	50	10
77	75	<50	10
78	125	<50	10
79	100	50	10
80	<50	<50	<10
81	<50	<50	20
82	<50	<50	<10
83	<50	50	10
84	<50	<50	<10
85	<50	<50	<10
86	<50	<50	<10

INDEX

- Alluvium.
- Float of silicified rock.
- Float of silicified rock and banded hematite-quartzite.
- Gossan with soil and/or shale.
- Silicified rock.
- Granite gneiss.
- Brecciated rock.
- Banded hematite-quartzite.
- Shale.
- G Gossan. /70 Strike and Dip.
- /70 Joints. —— Mineralised Fracture.
- Poorly mineralised Fracture.
- O1 Geochemical Sample point.
- Borehole.
- (900) Contours in feet.

(P.K. GHOSH et al)

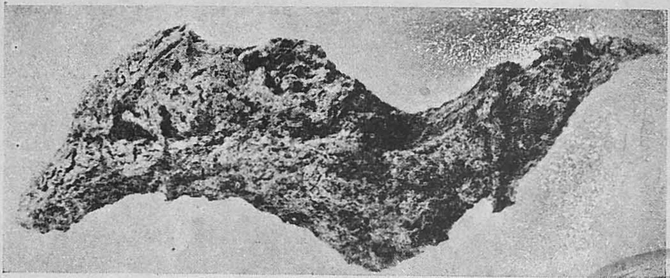


Fig. 1. Relief Limonite.

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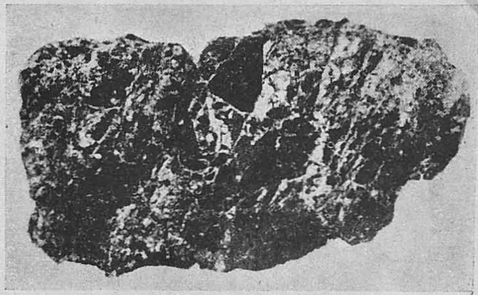


Fig. 2. Coarse Cellular Box-work.

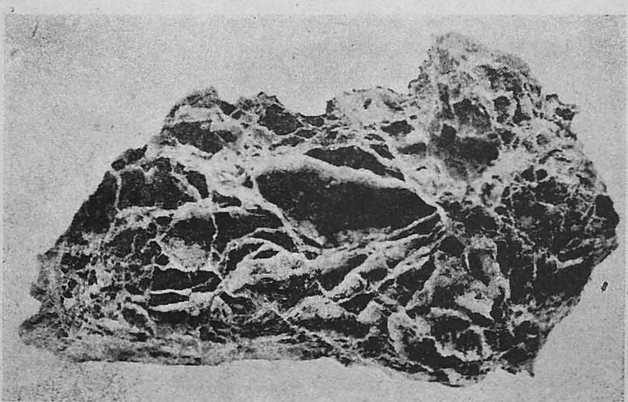


Fig. 3. Triangular and Trapezoidal Box-work.

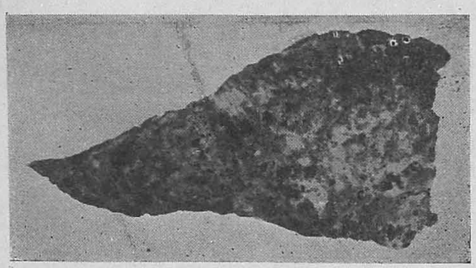


Fig. 1. Cubic Voids.

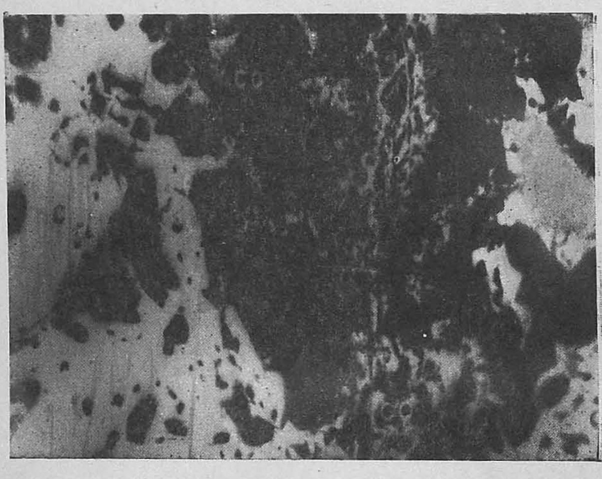


Fig. 2. Covellite Replacing Chalcopyrite.

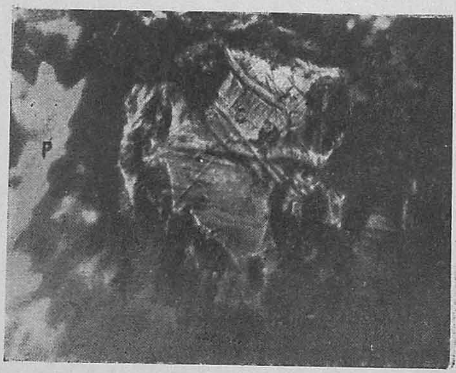
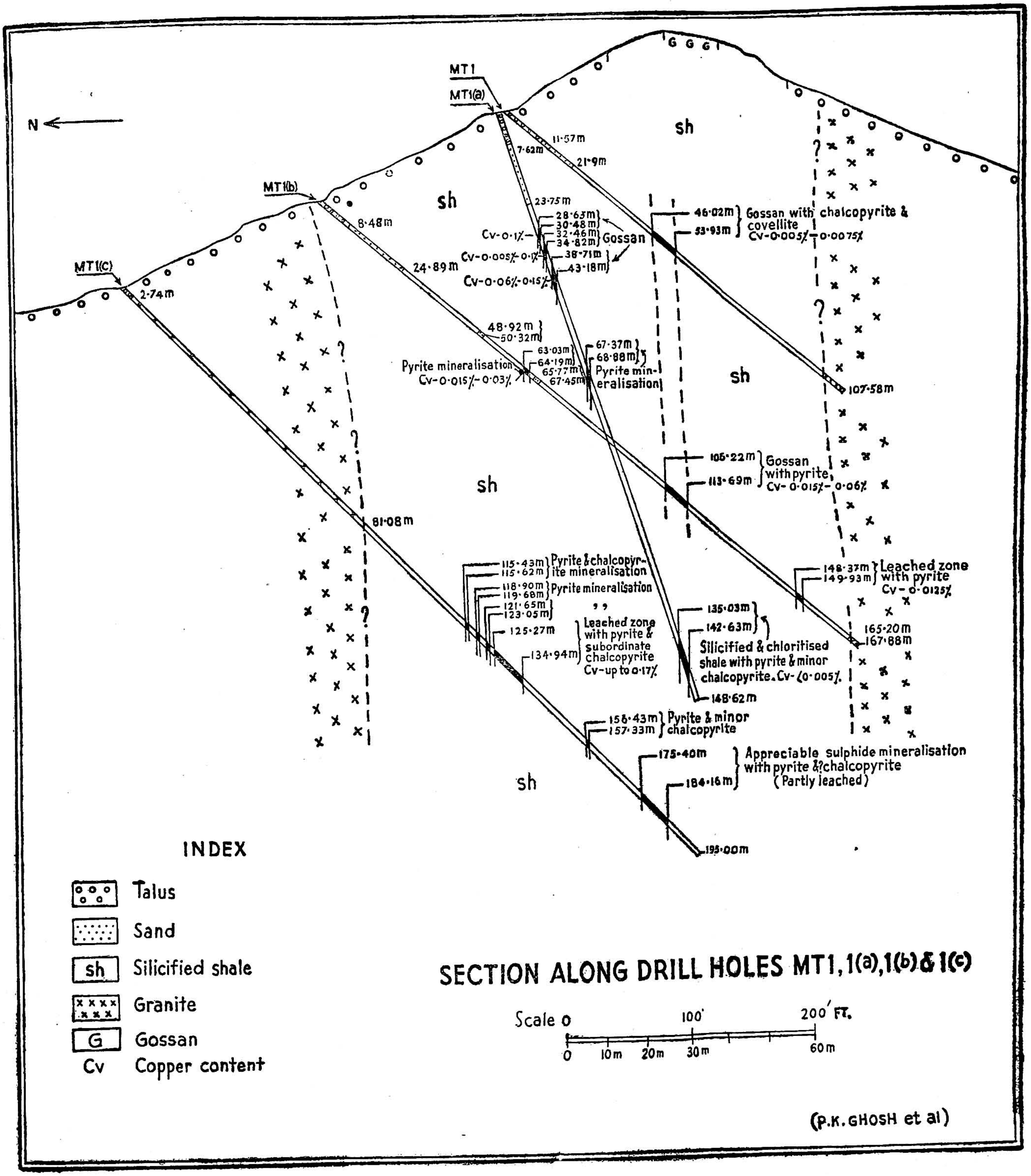


Fig. 3. Chalcopyrite in Pyrite.

PLATE 28



SECTION ALONG DRILL HOLES MT1, 1(a), 1(b) & 1(c)

practically all through in the oxidised zone. There is one definite mineralised horizon, namely 46 02 m. to 53.93 m. in MT 1 which has been encountered in MT 1b from 106.22 m. to 106.39 m. and in MT 1c from 175.40 m. to 184.16 m. This zone could not be observed in MT-1a because the hole had to be abandoned just short of it due to mechanical difficulty.

The following inferences may be drawn from the data obtained by drilling :—

1. Extensive sulphide mineralisation has taken place in the area.

2. Chalcopyrite is one of the constituents of mineralisation as observed in MT 1 at 49. 68—53. 93 m. ; MT 1a at 135. 03—148. 62 m. and MT 1c at 115. 43—115. 62 m., 127. 83—128. 41 m., 128. 96—133.64 m. etc.

3. Oxidation and leaching have gone very deep, even below a depth of 150 m. from the surface.

4. Observed sub-surface values of copper rise rapidly with depth. Compared to the mean background value 0.005 per cent, in the area, this increase is of the order of 4 to 20 times, at places even 50 times. This is significant, especially in the oxidised zone.

5. The main mineralised zone which showed chalcopyrite and covellite replacing chalcopyrite in borehole MT 1 (46.02—53. 93 m.) continues downward and has been intersected in boreholes MT 1b (106.22—113.69 m.) and MT 1d (175.40—184.16 m.).

CONCLUSION

On the basis of the evidences obtained during the course of the investigation, from field observations, laboratory tests and drilling, the existence of sulphide mineralisation with sulphides of copper as constituents has been established. But it has not been possible to reach the primary zones of mineralisation in view of the deep oxidation and lea-

ching. The potentialities of the belt can only be assessed after putting down deep holes at suitable places so as to intersect the primary zone of mineralisation.

ACKNOWLEDGEMENTS

The authors express their thanks to Dr. A. G. Jhingran, Director, Geological Survey of India, and Dr. John P. Albers of the United States Geological Survey for their valuable suggestions and guidance during the course of the investigation.

COPPER-LEAD-ZINC MINERALISATION NEAR MAMANDUR, SOUTH ARCOT DISTRICT, MADRAS

By

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Geological Survey of India.

(With Plates 29-30)

ABSTRACT

Copper-lead-zinc mineralisation occurs near Mamandur, South Arcot district along a sheard contact zone between banded garnetiferous quartzo-felspathic gneiss and granite gneiss in amphibolite, hornblende-granulite and garnet-plagioclase rock. The mineralisation along the limb of a regional anticlinal flexure is indicated by malachite encrustations and gossan. The ores comprise chalcopyrite, malachite, azurite, galena and sphalerite. The lodes strike in a general N.35°E. direction dipping at 55° to 65° to the south-east. The lodes from the trenches gave, on assay, a combined metal content of about 5 per cent of copper, lead and zinc with a maximum of 30.4 per cent zinc, 2.90 per cent lead and 0.94 per cent copper. A shallow angular drillhole in the northern portion of the area intersected a 3.41 m. wide base-metal rich lode which yielded weighted average assays of 0.34 to 0.41 per cent copper, 6.26 to 7.28 per cent zinc and 1.35 to 15.46 per cent lead. The second drill-hole cut through a chalcopyrite rich mineralised zone of about 13 m. in width carries sphalerite and galena in some amounts. The traced strike length of mineralisation is only about 500 m. The multimetal aspect of mineralisation and the rich lodes met with in the drill hole are encouraging. The mineralisation which is probably of hypothermal class appears to have been localised in the shear planes. The drag folds in the formations are the favourable host rocks.

INTRODUCTION

The copper occurrences in South Arcot district, Madras State was brought to light during the course of a mineral survey carried out by the author (1957-58). A preliminery investigation of the occurrence was carried out including regional mapping of an area of about 661 sq. km.

in which the copper occurrences are located, on scale 1:63, 360 to trace the extent of mineralisation. A detailed investigation of the occurrence was taken up by the Geological Survey of India during 1959-60. An area of about 732 m. × 335 m. around the copper deposits was mapped on plane table on scale 1:1,200. A geochemical soil sample survey was followed by trenching and systematic sampling of the lodes to evaluate the grade of the ores. Exploratory drilling was taken up in 1960-61 to assess the strike and depth extension of the deposit, as also the tenor of the lodes at depth for its economic workability.

The occurrence is located within the limits of the Kanankadu R. F. area and about 2.4 km. S. S. W. of the village Mamandur (Vadamamandur) (12°00′ : 79°00′ ; 58I/13), in Kallakurichi *taluk.* The area is reached from Tirukoilur and Chinnasalem Railway stations on the Southern Railway *via* Attiyur which is about 32 km. from Tirukoilur.

The area is flat with an average elevation of 152.4 m. (500 ft.) above m. s. l. and is marked to its west by the Kalrayan group of hills. It lies in the drainage basin of the Ponniar river.

GEOLOGICAL FORMATIONS

The area forms a part of the Peninsular Archean complex and comprises granite gneisses and charnockitic rocks interbanded with older metamorphics (Pl.29). The formations may be classified as follows.—

Pre-Cuddapah (?)	——	Basic Dykes.
Arcot Granite (younger type)	——	Pegmatite and quartz vein, Granite gneiss.
		Charnockitic rock.
Older metamorphics (Dharwars)		Garnet-sillimanite quartzo-felspathic gneiss. Garnet-plagioclase rock (Meta-anorthosite,). Quartzite, hornblende-granulite and amphibolite.

The dominant country rock around the copper occurrences consists of a greyish, medium to coarse-grained biotite-granite gneiss which carries bands of charnockitic rock and appears to be the equivalent of the younger granite in the peninsula *i.e.* the Bellary granite. It actually seems to represent an admixture of the older peninsular gneiss and the younger granite which cannot be differentiated easily. The rock at places is feebly foliated and appears to be a gneissic granite. Rocks of the charnockitic group generally rich in biotite form persistent zones in the area. Hornblende-granulite occurs as bands which are of small width near the workings and may be crushed and grade into amphibolitic types. Pink grey to dark coloured garnet-plagioclase rocks of the nature of meta-anorthosites are seen as somewhat impersistent bands associated with the hornblende-granulites. The rock is chiefly made up of garnet and plagioclase of basic composition and carries scapolite near its contact with granitic rock. Quartzite-bearing magnetite occurs as persistent bands extending in a general north-east direction. Fine to medium-grained garnet and sillimanite-bearing quartzo-felspathic gneiss which may be a paragneiss, form a prominent band of about 152.4 m. (500 ft.) width near the old workings ; it extends for about 4.8 km. (three miles) in a general north-easterly direction. Basie dykes of dolerite cut across the above formations.

STRUCTURE

The regional strike of foliation of the rocks is N.E.-S.W. with the oliation planes dipping at about 65° to the south-east. From the foliation dips of the rocks, a regional anticlinal flexure plunging in a general north-east direction could be deciphered. There is, however, no repetition of any particular lithological horizon on either side of the fold axis to confirm this. The copper mineralisation occurs in the south-eastern limb of the anticlinal flexure.

The rocks around the old copper workings strike in a general N.35°E.—S.35°W. direction dipping at angles around 65° towards south-east. The garnetiferous quartzo-felspathic gneiss (streaky gneiss) and the granite gneiss (massive gneiss) are sheared at their contact and thrown into drag folds. The granulites in this zone show good drag

fold effects of both dextral and sinistral type and a convergence of the two is observed on the Mamandur hill. Three prominent faults striking in a general north-south direction and dipping at angles of 70° to 80° towards west traverse the above rocks and have significantly displaced the contacts of the streaky and massive gneisses sinistrally. The slickensides along the fault planes show lineations plunging at 30° to the south.

MINERAL DEPOSITS

The mineralised zone is localised along the contact zone between garnetiferous streaky gneiss and biotite- bearing granite gneiss. It extends in a general N. N. E. to N. E. direction. The mineralisation is indicated on the .581 hillock and surroundings by encrustations of malachite while in the northern portions it is shown up by highly limonitic bands of the nature of gossans. The sulphide mineralisation is in the form of streaks, segregations and veins in the hornblende-granulite, amphibolite, garnet-plagioclase rock and also in the garnetiferous quartzo-felspathic gneiss as seen from the drill cores.

Mineralised garnet-plagioclase rock forms bands of about three metres (10 ft.) width. The gossan is very compact and made up of ferruginous matter, quartz and garnet. Limonitic boxwork is also observed at some places and it contains appreciable amount of manganese. The gossàn band shows dextral *en echelon* shift and is associated with a fine-grained quartz-spinel (?) rock. The mineralisation is traced for about 400 m. (1,500 ft.) while further on, the area is under soil cover and silt of the Mamandur tank. The lodes strike in a general N.35°E.—S.35°W. direction dipping at about 55°—65°to the south-east.

Mineralogy of the Ores : The ore minerals comprise chalcopyrite, malachite, azurite, galena and sphalerite. Veins of opalescent quartz, which traverse the amphibolite in the old workings, carry the base metal sulphides. The sulphides form veins up to about 2.5 cm. in width at places while in one of the trenches made on the .581 hill, 0.9 m. (three ft.) wide lens of sphalerite-rich zone was noticed. The lead and zinc sulphides dominate the copper sulphide in the lodes as seen from the assay values of the samples from the surface. The quartz-spinel rock may be of the nature of a gangue and may possibly serve as an indicator for ores in this area.

The amphibolite in the zone of mineralisation shows development of biotite as thin bands about 1.25 cm. in width, towards the contacts of the sulphide bearing quartz veins. The felspar in the streaky gneiss at the footwall zone is also altered at places to kaolin and sericite. The diopside in garnet-plagioclase rock in this zone is altered to tremolite and plagioclase to calcite. These changes appear to have been brought about due to the influx of hydrothermal solutions during mineralisation.

Old Workings : A few ancient workings of copper-ores can be seen on the ·581 hillock, extending along a general N. N. E. direction for about 61 m. (200 ft.). The workings show thick encrustations of malachite along the joint planes of the country rock. The ancient miners seem to have followed the hornblende-granulite which bears copious encrustations of malachite while the gossan bands which rarely show malachite, seem to have escaped their attention. The central working is about 7.6 × 4.6 × 3 m. (25 × 15 × 10 ft.). The dumps are not large enough as to suggest that the workings had been developed to any significant depth. Light porous slags, with long clay pipes were observed about 1.6 km. north-west of Periakolliur in the tank bed, from which it appears that smelting was carried out in this area in ancient times.

PROSPECTING

(A) *Geochemical :* In order to delineate the limits of mineralisation, geochemical soil sample survey was carried out by laying a number of lines across the zone of mineralisation and samples were collected at intervals (Pl. 30). The analytical values for copper when plotted graphically brought out anomaly zones corresponding to the exposed zone of mineralisation.

(B) *Trenching* ; A few trenches were made across the mineralised portions to expose the lodes and were sampled systematically. The samples, on assay, gave the following values for copper, lead and zinc.

(1) copper — 0.2 to 0.94 %

(2) lead — 0.3 to 2.9 %

(3) zinc — 0.39 to 30.04 %

Most of the samples showed high zinc values together with appreciable values for ,lead and low values for copper. The average content of the three sulphides from all trenches together was found to be about 5 per cent.

(C) *Drilling* : Exploratory drilling was taken up to confirm the extension of the lodes at depth and for proving the strike length of the deposit. Four angular drill holes were proposed in the first instance of which two have been completed so far.

Drill hole No. 1 : The first drill hole located east of a gossan band in the northern portion of the area was drilled at an angle of about 48°. It intersected at a depth of about 18.3 m. (60 ft.) a base metal rich lode 3.2 m. (10 feet 9 inches) in width. The ore when assayed gave the following values for copper, lead and zinc. (Table-1)

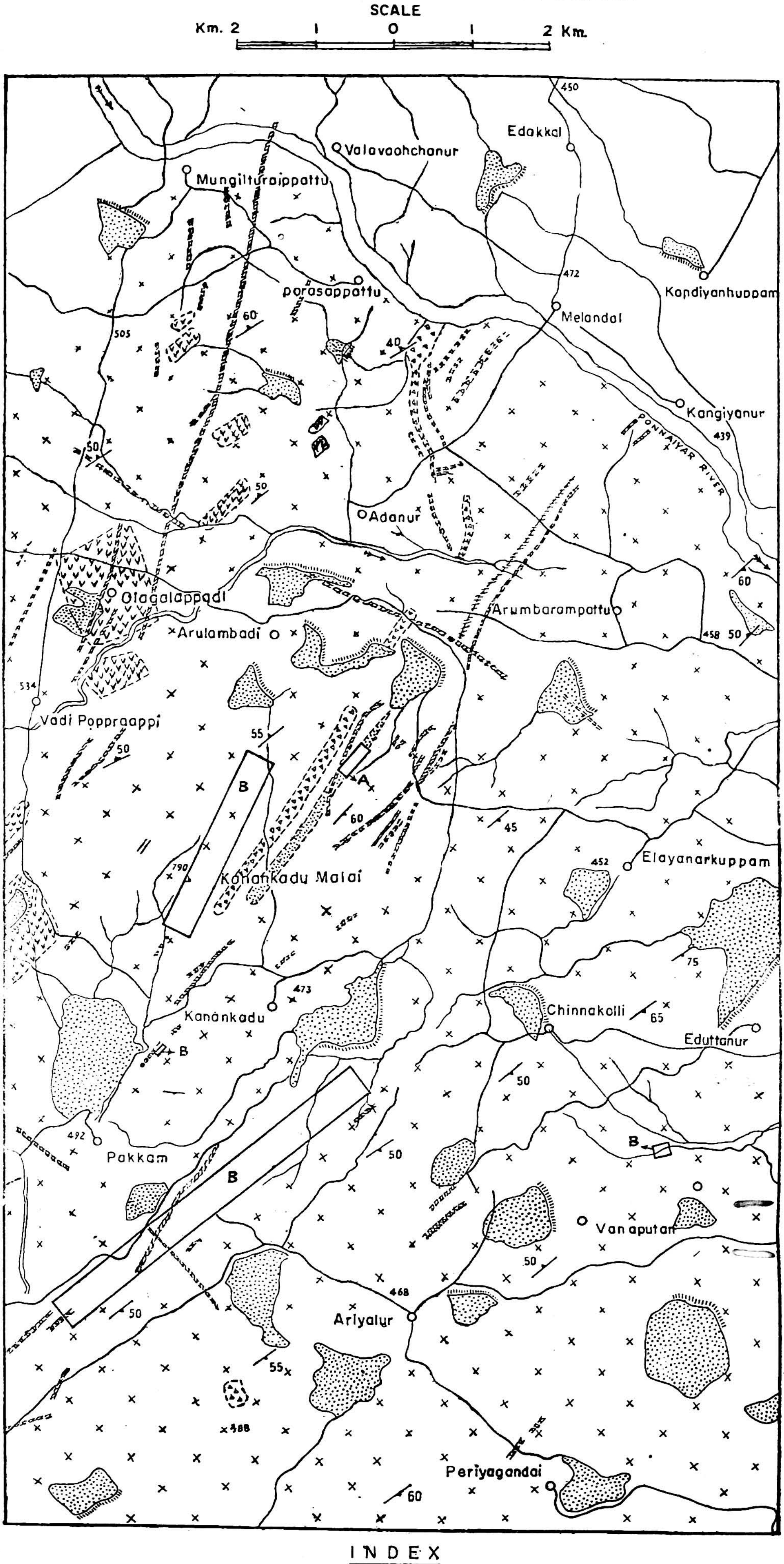
Table—1

Sample No.	Footage	Cu%	Zn%	Pb%	Weighted average Assay.		
					Cu	Zn	Pb
1.	62'0"—62'6"	1.18	6.17	4.2	0.338	6.266	15.458
2.	62'6"—63'0"	0.42	4.88	9.9			
3.	63'0"—64'0"	0.13	5.55	21.8			
4.	64'0"—64'9"	Nil	8.21	18.1			
5.	68'0"—69'0"	0.20	10.79	0.4	0.407	7.287	1.35
6.	69'1"—70'4"	0.60	4.97	2.2			

Drill hole No. 2 : The second drill hole, located south-east of the old workings on the .581 hill, was drilled at an angle of 46° in a general N. 50° W. direction. The lode was intersected at a depth of about 32.2 m. (107 ft.). It is about 18.3 m. (60 ft.) in total width and is generally rich in chalcopyrite. It carries some amounts of galena and sphalerite in the first 3 m. (ten feet) while chalcopyrite forms streaks,

PLATE 29

GEOLOGICAL MAP OF PORTIONS OF KALLAKKURICHCHI TALUK, SOUTH ARCOT DISTRICT, MADRAS, SHOWING THE COPPER AND PYRITE DEPOSITS.



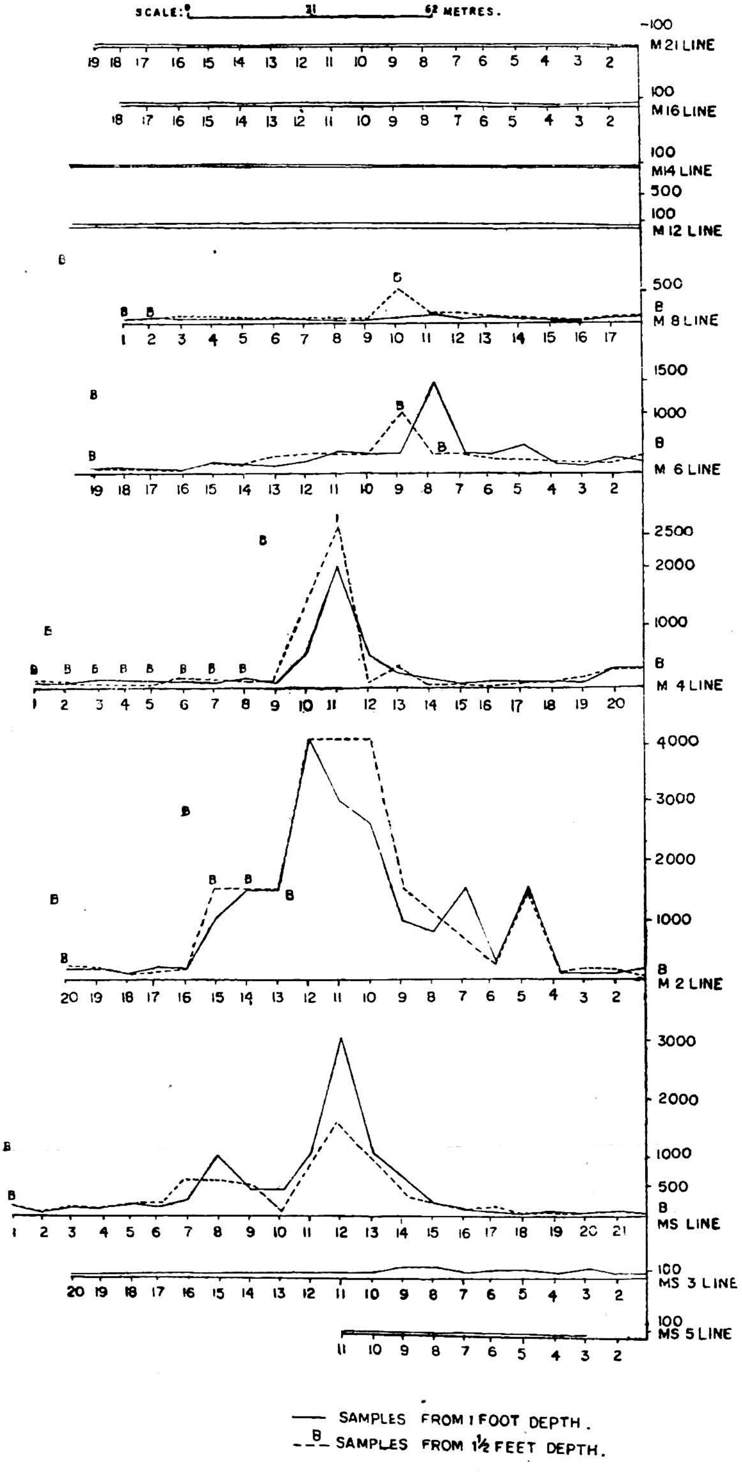
INDEX

- Unmapped
- Basic dyke
- Biotite-granite gneiss
- Charnockitic rock
- Garnetiferous quartzo-felspathic gneiss
- Garnetiferous plagioclase rock
- Tremolite-talc rock (altered ultrabasic rock)
- Magnetite-quartzite
- Hornblende-granulite
- Strike and dip of foliation
- Old copper working
- A Copper mineralised area
- B Pyrite mineralised area

(N.G.K. MURTHY)

PLATE 30

GEOCHEMICAL PROFILE FOR COPPER ALONG THE TRAVERSE LINES IN THE AREA AROUND THE COPPER OCCURRENCES NEAR MAMANDUR, SOUTH ARCOT DISTRICT, MADRAS.



(N.G.K. MURTHY.)

stringers, disseminations and veins up to a maximum width of about 6 mm. ($\frac{1}{4}$ inch). An examination of the drill cores reveals that the lode is rich in copper.

The first drill hole revealed lead-zinc mineralisation with smaller amounts of copper while the second drill hole which had gone deeper indicated copper rich mineralisation with small amounts of lead and zinc. This is possibly suggestive of depth mineralogical zoning of an upper lead-zinc zone passing into a copper rich zone at depth.

ORE GENESIS

The copper-lead-zinc mineralisation in the Mamandur area occurs at the contact zone between a banded garnetiferous quartzo-felspathic gneiss and a massive type of granite gneiss along the limb of a regional anticlinal flexure. The rocks in this zone have been sheared and drag folded.

The compact formations have been rendered favourable for mineralisation under the influence of shearing and drag folding during regional folding and metamorphism. The streaky gneiss containing high grade metamorphic minerals occurs as a distinct band for about 4.8 km. (three miles) and seems to represent a prominent shear zone. A system of radial faults traversing the rocks have helped to make the streaky gneiss fissile and caused development of fractures in the rocks. The shear planes have been mineralised in preference to the fault planes. The mineralising hydrothermal solutions which came up along the fractures caused metallisation in the hornblende-granulite, amphibolite and the garnet-plagioclase rock bands lying along this zone. The mineralisation which is intense and has a width of about 12.2 m. (40 ft.) near the old workings appears to have been brought about due to a convergence of the dextral and sinistral drag folds. Thus the drag fold axes and the shear planes along the contact zone seem to have served as loci of mineralisation in the Mamandur area. The deposit is of the nature of an epigenetic hydrothermal mineralisation, probably of hypothermal nature.

CONCLUSIONS

The strike length of the base metal mineralisation in the Mamandur copper area traced 460 m. (1,500 ft). But further on there are favourable indications of mineralisation which has to be proved by more drilling. The width of the zone of mineralisation near the old workings is about 12. 2 m. (40 ft.) while in the north-eastern portion of the area it is about three metres (ten feet). The two drill holes completed in the area have shown rich base metal mineralisation. The persistence of the lodes at depth should be proved by a deep drill hole.

Near Toluvantangal (11°56′ : 78°58′) about 6.4 km. (four miles) S.S.W. of the above zone of mineralisation, a 4.8 km. (three miles) long pyrite belt was traced by the author. At Odiyandal (11°57′ : 79°02′) a few kilometres further east, rich pyrite mineralisation was observed in a well section. In both the occurrences a small amount of copper was found. The quartzite band extending through the Kanankadu Malai is fractured and subsequently veined by limonite. Malachite staining has also been observed along other zones of disturbance in the area. A complete investigation of all these occurrences by drilling will help in assessing the reserves of the base metal ores in this area. Thus the occurrence of rich copper-lead-zinc multi-metal lodes near Mamandur, though of small strike length, is quite encouraging and warrants further exploration.

A NOTE ON THE PRELIMINARY EXAMINATION OF AN OCCURRENCE OF COPPER IN THE VICINITY OF THANEWASNA, CHANDA DISTRICT, MAHARASHTRA.

BY

B. S. KARKARE,
Department of Geology and Mines,
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(With Plate 31)

ABSTRACT

Preliminary survey carried out in Thanewasna area (19°05′ : 79°44′), Chanda district, has shown the presence of an interesting copper deposit. The rock formations in the area belong to the Archaean group and consist of gneisses, basic intrusives and pink granite with associated pegmatite and quartz veins. The mineralisation is noted in a zone, about 1,650 m. long north of Thanewasna village and having a width of about 30 m. The mineralisation is of a poor disseminated hydrothermal type associated with lead and zinc minerals. Microscopic study has indicated the presence of chalcopyrite, pyrite, covellite, chalcocite and malachite. The surface samples analysed 0.1 to 0.8 per cent copper. The upper zone is leached and shows malachite and presence of limonite and other iron oxides. Mineralisation is seen to occur in quartz veins and basic rocks, being confined chiefly to fractured zones.

INTRODUCTION

Existence of copper ore was reported from Thanewasna area (19°05′ : 79°44′), Chanda district, in March 1961 and the area was prospected by the author. The results of preliminary geological mapping and sampling are encouraging.

Location and Accessibility

Thanewasna is a small village situated on the north bank of the Wainganga river in Chanda *tehsil* of Chanda district. The area is

accessible from Mul (on Nagpur-Chanda road) by a 32 km. long fair weather cart track.

Previous Work

The area had been geologically mapped by the Geological Survey of India. The rocks were grouped under the general term 'metamorphics' and no detailed account was given. The local inhabitants, however, stated that some old prospectors had opened a few shallow pits in the area about 50 years back. Neither the identity of the prospectors nor the exact time of the old working could be ascertained. The area has been marked as disused mine in the sheet No. 56 M/9.

Physiography

The area in general, forms a plain country with an average elevation of 180 m. above the mean sea level. There is only one prominent ridge north of the Thanewasna village, extending over a distance of about 1,300 km. in a N.N.W.—S.S.E. direction and having a maximum elevation of 30 m. above the surrounding plains. The drainage pattern is governed by the Wainganga river and its tributaries. Excellent rock exposures are found in the hill and in the bed of the Wainganga river.

Nature of Work Done

A preliminary geological map of the area around Thanewasna covering about 10 sq. km. was prepared on 1 : 7,920 scale. The hill to the north of Thanewasna where promising indication of mineralisation was noticed was mapped on 1:600 scale by tape and compass survey. About 50 samples were collected from the mineralised zone and 40 of these were analysed for copper, lead and zinc. The polished ore sections and thin sections were studied at the Department of Geology, Nagpur University and also at the laboratory of the Indian Bureau of Mines.

GEOLOGY

Rock formations in the Thanewasna area belong to the Archaean system and comprise metamorphic and intrusives (Pl. 31) as given below :—

Alluvium		Recent, sub-Recent.
Younger basic intrusives		
Pink granite with associated pegmatite quartz veins and granite gneiss		ARCHAEAN
Older basic rocks		
Older hornblende-gneisses	Epidiorite Pyroxenite Amphibolite	

Light coloured hornblende-gneisses are prominently exposed to the north-east, east and south-east of the Thanewasna hill and similar rocks are exposed about 800 m. to the west. These gneisses are intruded by coarse to fine-grained basic rocks like pyroxenites, epidiorites and amphibolites. All along the western flank of the hill, exposures of a silicified veined green rock are seen. This rock contains considerable chlorite and amphibole, probably altered, mylonitised epidiorite or amphibolite, striking N.N.W.—S.S.E. with foliation dipping at 65° to 75° W.S.W. These rocks are intruded by a pink coloured granitic to granodioritic rock, carrying pink soda felspar, microcline, plagioclase, hornblende and a little quartz. These are fractured and intruded by pegmatite and finally by quartz veins which were possibly the mineralisers. Pegmatites, aplites and quartz veins appear to be related to the pink granite and have an intrusive relationship to gneisses and mylonitised epidiorites. The rocks, particularly the pink granite, the chlorite-amphibolite type of basic rock and the vein quartz all show signs of great disturbance, brecciation and faulting. There is evidence of hydrothermal mineralisation in the fractured granite and the green chloritic mylonitised and silicified rock occurring all along the western flank of the hill. Effects of hydrothermal activity like large scale silicification, chloritisation, epidotisation and kaolinitic alteration can be noticed in the area north of Thanewasna. Dissemination of copper with lead and zinc mineralisation has taken place in the fractured and green chloritic mylonitised rock. Disseminations of chalcopyrite and

pyrite can be noticed very often filling minute irregular cavities in quartz veins, granite and the green mylonite. It seems that there has also been disturbance and fracturing of the rocks subsequent to mineralisation as many of the fractures are absolutely barren. Mineralisation seems to have been controlled by the structural features like faulting and brecciation.

Extent of Copper Mineralisation

Copper mineralisation has been noted in a belt extending from the Lahn river bed, south of Thanewasna village up to a *nala* flowing in south-easterly direction, at the north end of the Thanewasna hill, intermittently for over 1·6 km. The width of the mineralised zone is variable from a few centimetres to about 30 m. The fractured quartz vein, mineralised green mylonite, pink granite and the rocks showing kaolinitic alteration all seem to have been leached in the higher portion of the hill. Primary ores like chalcopyrite and pyrite are partially altered.

The green chloritised basic rock (altered epidiorite) in thin sections is found to be traversed by thin veins of quartz. The cavities in the green mylonitised rock and the quartz are filled by limonite.

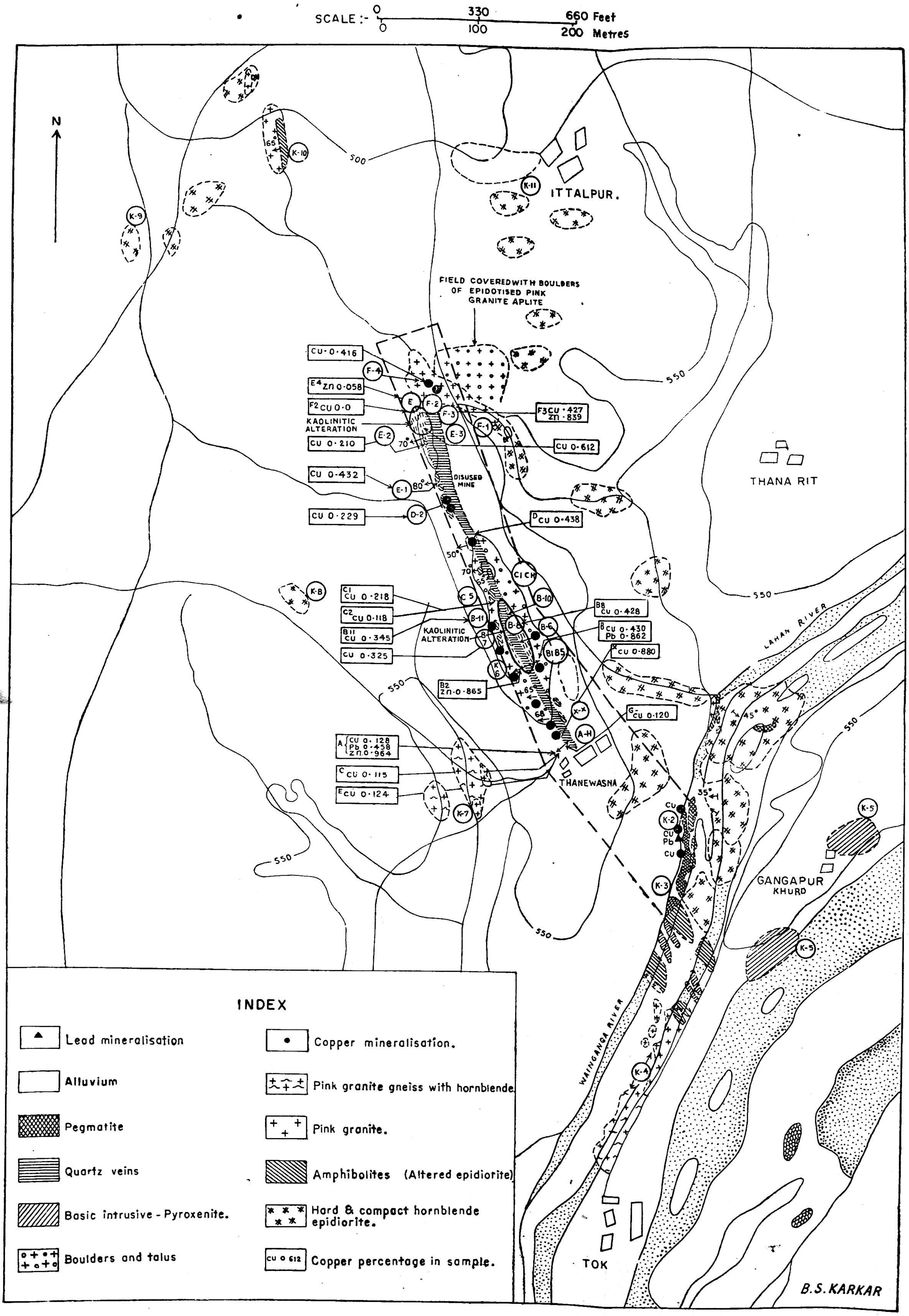
ORE-MICROSCOPIC STUDY

A number of specimens of mineralised quartz rock, granite and green mylonite were examined under the ore-microscope and the presence of the following minerals was noted :—

1.	Chalcopyrite	—	Occurs in irregular shape and most of the grains are less than 2 mm. across.
2.	Pyrite	—	-do-
3.	Covellite	—	Replaces chalcopyrite along periphery.
4.	Chalcocite	—	Probably replaces chalcopyrite.
5.	Malachite	—	Occurs as encrustations in fractures.
6.	Limonite	—	Occurs in cavity filling of pyrite and chalcopyrite and fracture planes.
7.	Goethite	—	Replaces chalcopyrite and fills cavities and fractures.
8.	Hematite	—	Fills cavities, veins and fractures.

PLATE 31

GEOLOGICAL SKETCH MAP OF THANEWASNA COPPER AREA, CHANDA DISTRICT



The study indicates that the mineralisation is associated with quartz and is controlled by some pattern of fractures and cavities in the granite, green mylonite and vein quartz. The mineralisation is broadly of the same period as that of quartz but it is a little later, since chalcopyrite occurs mostly as cavity filling in the quartz ; malachite is probably just a surface encrustation. Absence of a prominent gossan and poor supergene enrichment of chalcopyrite and pyrite to chalcocite and covellite, presence of unreplaced chalcopyrite and pyrite in exposed ore at base of the hill indicate that there has not been much enrichment and that the possibility of getting any significant supergene enriched ore below ground level is remote. There may be, however, some oxidised or supergene ore above the ground surface in the higher portions of the hill though the upper zone seems to have been considerably leached.

Regions indicating kaolinitic alteration show signs of considerable mineralisation and the chances of getting better grade ore below the superficial, leached and oxidised zone at depth appear to be fair.

The existing fractures and cavities in rocks have been rather poorly mineralised but at lower levels mineralisation may improve.

RESULT OF CHEMICAL ANALYSIS

A number of samples from the area were analysed by Dr. Dhareswar in the departmental chemical laboratory. The results have been plotted on the geological map from which it is evident that the mineralisation has taken place along quartz veins, mylonitised zone and fracture zone in the pink granite.

The copper values range from 0·1 to 0·8, lead 0·45 to 1·21 and zinc up to 0·85 per cent. Lead and zinc were found only in a few specimens. The copper values have been found in a zone of about 1·6 km. long and up to 30 m. wide. The surface samples, which have been partially leached of the copper content have given copper values up to 0·70 per cent. Tnere seems to be a fair possibility of finding favourable areas with better grades of copper at greater depths, particularly in the zone of kaolinitic alteration. The area deserves further exploration.

COPPER DEPOSITS NEAR KALYADI, HASSAN DISTRICT, MYSORE.

By

N. G. K. Murthy,
Geological Survey of India.

(With Plates 32-33)

ABSTRACT

Copper mineralisation occurs near Kalyadi in a narrow strip of the Dharwar metamorphics associated with Peninsular suite of granite gneisses and younger pink granites. It is in the form of thin and sporadic malachite encrustations and limonitic boxwork in quartzites and quartz-schists. Malachite, azurite, chalcopyrite in the vein quartz debris, pyrite and chocolate to orange coloured limonite are the minerals met with. The lodes appear to have steep north-easterly dips and a low pitch to the north, similar to the enclosed formations. The mineralisation seems to have been localised by the cleaved and fractured quartzite with the drag folds in the latter also playing a part in the formation of the ore along the drag fold axes. The total strike length is less than 800 m. The evidences of ancient metallurgical activity and the geophysical anomalies are very encouraging features. Drilling has been commenced recently in this area.

INTRODUCTION

An investigation of the copper deposits near Kalyadi, Hassan district, Mysore, was carried out by the author during 1959-60. An area of about 130 × 550 m. containing the old workings for copper-ore was mapped on 1:2,400 scale using the plane table, in order to study the nature and controls of mineralisation. Regional mapping on 1:63,360 scale of the area around the workings and a geochemical soil sample survey were also carried out during the course of the investigation. Exploratory drilling was taken up in July 1961.

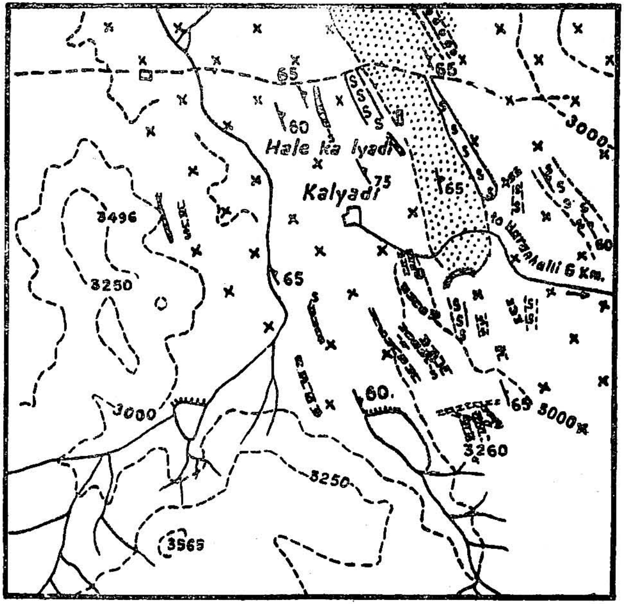
The occurrence of copper-ore near Kalyadi appears to have been brought to light for the first time by Dr. B. P. Radhakrishna of Mysore

PLATE 32

GEOLOGICAL MAP OF THE AREA AROUND THE COPPER WORKINGS NEAR KALYADI,

Scale

Km. 2 1 0 1 2 Km.



INDEX

- Basic dyke.
- Pink gneissic granite.
- Granite gneiss
- Steatite-schist (altered ultrabasic rocks)
- Quartz-schist and Quartzite.
- Sericite-schist
- Amphibolite
- Strike and dip of foliation.
- Old copper working

(N.G.K. MURTHY)

Geological Department in 1937-38.

The copper occurrence is located about 200 m. south-east of the village Kalyadi (13°14′ : 76°09′ ; 57C/4) in the Arsikere *taluk* of Hassan district, on the eastern flanks of a low ridge, locally known as Belligutti, which forms the north-western spur of hill ·3260. It is reached from Arsikere R. S. on the Bangalore-Birur metre gauge section of the Southern Railway *via* Haranhalli, a village about eight kilometres from Arsikere on the Arsikere-Hassan road.

The area in which the copper deposits are located has an average elevation of about 880 m. (2,900 ft.) above m. s. l. and is surrounded on all sides by prominent N.W.-S.E. trending hills. The general direction of drainage of the area is to the north into the Vedavalli river.

GEOLOGICAL FORMATIONS.

The area forms part of the Archaean complex of Mysore and lies a few kilometres off the Nuggihalli schist belt. It is constituted of Dharwar metamorphics associated with ultrabasic intrusives amidst peninsular suite of granite gneisses (Pl. 32). The formations have been tentatively classified as follows :—

Pre-Cuddapah (?)	...	Basic dykes.
Closepet granite (Banavar granite)	...	Pegmatite, quartz vein, Pink gneissic granite.
Peninsular gneiss	...	Biotite-bearing granite gneiss.
Dharwars	...	Steatite-schist (altered ultrabasic rock) quartzite and quartz-schist. Magnetite-quartzite Sericite-schist, Phyllite Amphibolite.

The area around the copper occurrence is made up mostly of a greyish, well foliated granite gneiss which is generally very much crushed and highly micaceous. The meta-sedimentary and altered ultrabasic rocks occur interbanded with the granite gneiss. Compact dark greenish amphibolite and greenish grey phyllite are seen as bands in the south-western portion of the area. Silver-grey to brownish sericite-schist carrying muscovite occurs in zones which are about 60 m. wide each and are traceable for appreciable distance. The rock is found chiefly along the foot wall of the workings. Quartzite of light brown to white colour forms the most important marker horizon in the area and extends as persistent bands in a general north-west direction. The rock is at places fissile and tends to be a quartz-schist when it may also carry thin partings of the mica-schist. It has a general pitted appearance and carries irregular voids, thin malachite encrustations and limonitic veins at places. A number of quartzite bands have been mapped of which the one occurring near the workings is the most important from the point of copper mineralisation. It is about 18 m. (60 ft.) wide. The rock is also cleaved and drag folded. Bands of greenish grey soft steatite-schist which appears to be the altered ultrabasic intrusive occurs commonly in this area, in linear bands. Compact and feebly foliated, coarse-grained pink granite locally known as Banavar granite occurs over a length of about 800 m. in the northern portion of the area. Veins of pegmatite and quartz traverse the above formations ; the latter often occur in an *en echelon* pattern. Basic dykes of dolerite form the youngest rock group in the geological sequence.

STRUCTURE AND METAMORPHISM

The general strike of foliation of the rocks is N. W.—S. E. with with the foliation planes dipping at about 70° to the north-east. No major structures are observed in the area mapped except for some sinistral drag folds exhibited by the steatite-schist north of the working. The rocks near the copper workings have been considerably disturbed and folded. A gently plunging syncline and an anticline along a general N. W.-S. E. trending axis has been traced. The quartzite band near the workings has been sinistrally drag folded as a result of which it appears to have been shifted to the west when followed from the southern portion of the area. Lineations plunging at about 20° to the north-west are observed in the quartzite. In the central portion of the

area the quartzites which are found both on the foot and hanging walls might have been connected up by a drag fold and separated owing to the emplacement of the granite along the drag axis. During the fold movements the rocks have also been sheared as is evidenced by the slickensiding and fissility developed in them. A number of joints along which there has also been some movement is observed in the quartzites.

The rocks show metamorphism of low grade equivalent to the chlorite isograd and are characteristic of the epizone.

COPPER DEPOSITS

Copper mineralisation is observed on the eastern flanks of the ridge south-east of Kalyadi along the contact zone between quartzite, sericite-schist and steatite-schist and is marked by the presence of a line of old workings. The mineralisation extends in a general N.W.—S.E. direction and is indicated by malachite coatings in the southern portions and by sparse malachite stains, limonitic veins and gossans in the northern portions.

A quartzite band, about 45 m. (150 ft.) wide in the southern portion shows numerous encrustations of malachite and thin limonitic patches and has been trenched very much by the ancients. The rock is fissile and may look like a sericite-quartz schist. The limonite masses in this rock are at places in a net-work pattern; and voids formed probably due to leaching of the original sulphides are commonly observed. Malachite and limonitic material are observed around the voids, along the joint and bedding planes and around the vein quartz in the quartzites. The quartzite extends for about 180 m. (600 ft.) where it is drag folded due to which it appears sinistrally displaced. Malachite is sparsely developed in this part of the mineralised zone and chocolate coloured limonite is commonly observed. In the northern portion towards the high ground, malachite splashes with chocolate coloured limonitic material have again been observed. A three metre wide band of gossan material is noticed, over distance of about 30 m. (100 ft.). The gossan which is porous and highly ferruginous appears to represent mineralised quartzite, though it does not bear any malachite. The mineralisation was traced up to a point about 180 m. south-east of the

Kalyadi school. Pyrite mineralisation has also been observed in the quartzite near the school as also near Vrundavanahalli village, to east of the old workings.

Ore minerals: The ores met with comprise malachite, azurite, chalcopyrite and pyrite besides orange and chocolate coloured limonite. The primary copper sulphide is not exposed on the surface anywhere although it can be seen in the vein quartz debris strewn around the workings. The pitted appearance and the limonite veins in the quartzite must have been the result of leaching out of the primary sulphides. In the corse recovered from the first drill hole, chalcopyrite associated with pyrite (with the latter dominating at places) occurs as streaks, stringers and veins in the quartzite with a width up to 13 mm.

Old Workings: A line of extensive old workings is noticed in the mineralised quartzite band for over a strike length of about 300 m. In the southern portion, four almost parallel workings are seen in a wide band of quartzite. From this end onwards a long line of almost continuous workings extends for about 180 m. where they turn to the south-west corresponding to the drag fold in the quartzite. From this it appears that the ancients followed the ore shoots and developed along the drag fold axis. In the northern portion of the area, a small working measuring about 3.6 × 2.0 × 3 m. is noticed, with thick malachite stains along the joint planes. Most of the workings are completely filled up by fine silty material thereby completely concealing the lodes. The highly silted up nature of the workings indicates that the workings are either very ancient or have been developed to such depths as to cause the walls to collapse. But no dumps of any significance are seen nearby. However, extensive slags are noticed in the valley south-west of the workings admixed with long clay pipes of the nature of retorts to suggest the existence of ancient metallurgical activity for winning copper in this area. This is also confirmed by the slags which on assay, have yielded about 0.12 per cent of copper.

No significant wall rock alteration is noticed in the schists on the surface. The granite gneiss in the workings has been sericitised at some places to such an extent as to approach a sericite-schist. The felspars in the granite gneiss towards the walls have also been altered to sericite and kaolin.

PROSPECTING

(a) *Geochemical :* In order to trace the extent of mineralisation beyond the workings, where the country is mostly under cover of soil, a few geochemical traverse lines were laid during the course of the work. The data obtained on analysis of the soil samples indicated the presence of anomaly zones towards the old workings, confirming the field observation that the mineralisation is only in the quartzite (Pl. 33).

(b) *Geophysical :* Following the completion of the detailed geological investigation, a geophysical survey of the area was carried out by a party of the Geological Survey of India headed by Shri K. R. Madhwa Simha. The survey has yielded a number of self-potential anomalies mostly near the old workings indicating the possible existence of sulphide rich lodes at depth.

(c) *Drilling* : In order to ascertain the continuity and nature of the lodes at depth, exploratory drilling was taken up in collaboration with the Deptt. of Mines and Geology, Mysore State, employing their diamond drill, in July 1961. The first drill hole was put down at an angle of 45° in a S.62°W. direction and was located at about 60 m. E.N.E. of the widest portion of the quartzite in the southern part of the area. It intersected a chalcopyrite-rich lode extending from 58-116 m. along its length. The mineralisation is mostly in the quartzite permeating a little into the wall rocks. Chalcopyrite associated with pyrite forms the chief sulphide constituents with small amounts of a dark grey sulphide which may be chalcocite. The assay results are awaited.

ORIGIN OF THE ORES

The occurrence of copper in the Kalyadi area is in a cleaved quartzite at its contact with steatite-schist, sericite schist and granite gneiss. The mineralisation seems to be localised along the limb of a minor synclinal fold plunging at about 20° in a N.30°W. direction. It is noteworthy that only the quartzite contacts are mineralised, indicating some kind of stratigraphic and lithlogical controls. The rocks also show evidences of slickensiding indicating that the contacts between the competent and incompetent rocks have been sheared. The mine-

ralising solutions traversed the cleaved and fissile quartzite and the sheared contacts and caused metallisation. The sinistral drag fold in the quartzite also appears to have helped in localising the ore formation along the drag fold axes. Thus the deposits seem to have been formed under both lithological and structural controls of ore formation. The lodes follow the bedding planes and the sheared contacts of the formations and therefore, may be taken to have the same structural attitude *i.e.* a steep north-easterly dip and a low pitch of about 20° in a general north-westerly direction.

CONCLUSIONS

A total strike length of about 650 m. of copper mineralisation has been traced from the surface indications in the Kalyadi copper area. The persistence of mineralisation at depth has to be proved by drilling, which is now in progress. The ancient metallurgical activity in the area appears to have been quite considerable as seen from the extensive slags and the retort-like clay pipes. Similar retorts have been recovered from other ancient base metal smelting centres in the country (Rajasthan and Andhra Pradesh). It is possible that mining in this area had been given up by the ancients owing to caving of the open cast workings, smelting difficulties or deterioration in the grade of the ore as not to make the recovery of the metal profitable. The results of the first drill hole in this area are very encouraging. An examination of the drill cores of the mineralised portions indicates that they are rich in copper. It is, therefore, considered that inspite of the limited strike length of the deposit the area may have potential copper deposits.

A NOTE ON THE COPPER DEPOSITS IN THE BOLANGIR-PATNA DISTRICT, ORISSA.

By

P. K. Chatterjee
And
B. N. Jayaram,
Geological Survey of India

(With Plate 34)

ABSTRACT

The note refers briefly to the examination of surface indications of copper sulphide mineralisation associated with lead-ore occurrences in the shear zone quartz and breccia veins in the Bolangir-Patna District of Orissa. Further mapping of the mineralised quartz veins followed by geophysical and geochemical investigations and by drilling, if necessary, are suggested.

Copper deposits of any size are not known to occur in Orissa. The discovery of the occurrence of copper deposits in the Bolangir-Patna district is, therefore, of some importance. The occurrence of lead-ore (galena) at several localities near Jolorpodor (20°24′ : 83°22′) and Baddipara (20°26′ : 83°22′) in the Saintala *Thana* area of the district had been reported earlier. Preliminary examination of these deposits indicated the presence of copper minerals along with the lead-ores (Pl. 34). Chalcopyrite, chalcocite, malachite and azurite associated with galena were seen in the mineralised quartz veins along a shear zone. The fissure-filled quartz veins have been traced over a total distance of about 29 km. but the surface indications of copper mineralisation could be seen only in a few quartz veins near Dummermunda (20°23′ : 83°22′) across a width of about 4.8 km.

Surface examination of the mineralised zone and a few shallow

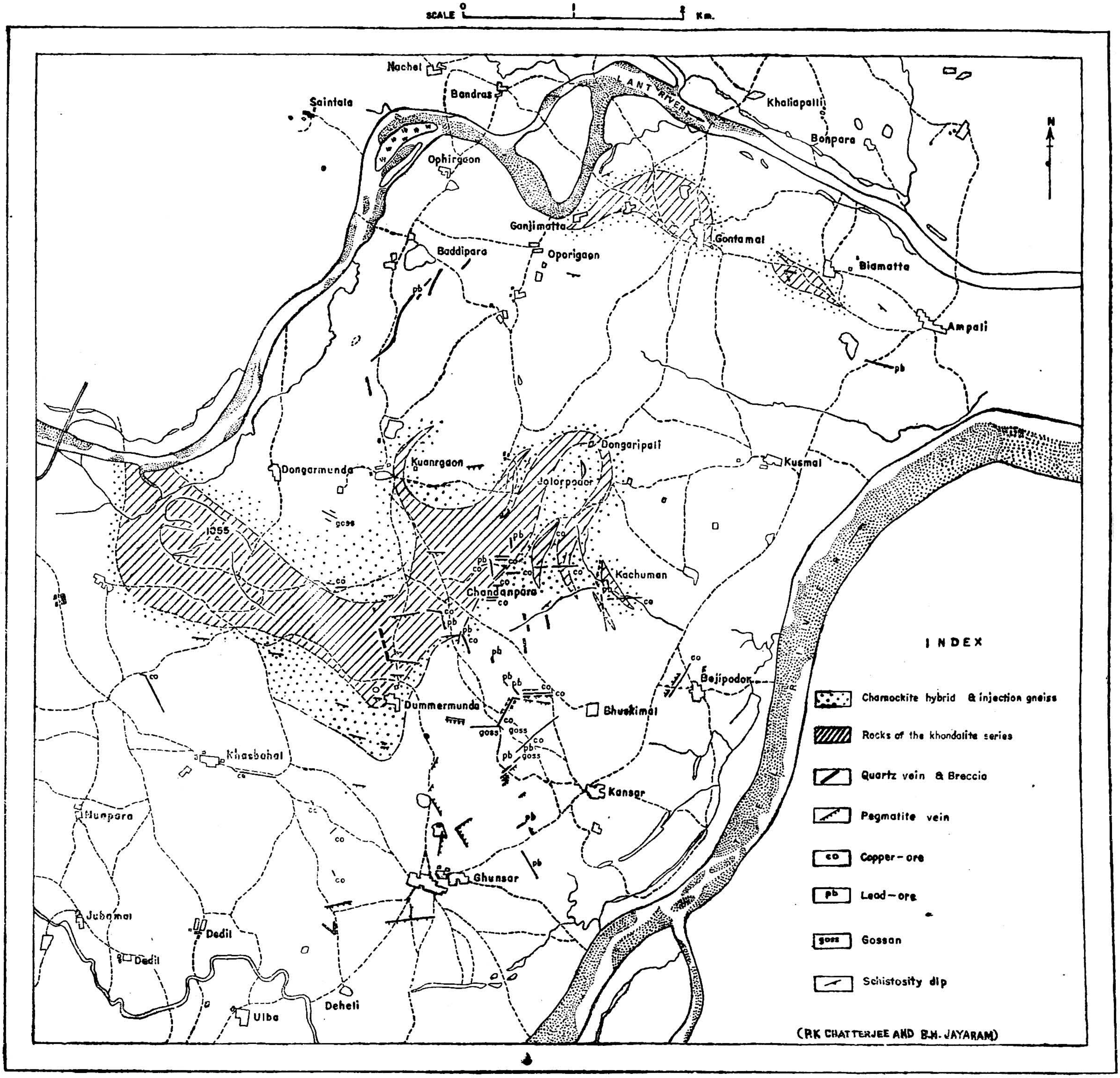
pits that could be put down during these investigations indicate that the mineralisation (with primary copper and lead sulphides) was through the agency of hot, igneous emanations. No outcrop of igneous body is seen in the vicinity of the mineralised area, but, evidences of widespread granitisation of the country rocks bear sufficient testimony to the igneous activities. The primary sulphides have undergone oxidation and supergene enrichment to some extent. The shear openings from the pattern of a network of intersecting veins in two directions *viz*. N.N.W—S.S.E. and east—west. The east—west fractures are invariably occupied by pegmatite veins which are barren and are presumably younger than the quartz veins which fill the N.N.W.—S.S.E. set of fractures and show the sulphide mineralisation. Within the general pattern of the shear fractures, the individual veins exhibit *en echelon* structure.

The lengths of quartz veins showing both copper and lead mineralisation vary from 00 to about 800 m The average depth of oxidation and the thickness of the secondary enrichment zones have not been determined. The average depth of the water table in this area is between 6.0 and 7.6 m.

Initially, strike mapping of all the mineralised quartz veins on a large scale is to be carried out. If a sufficient number of veins of more than 600 m. length are located, further investigations employing geophysical and geochemical methods may be followed.

PLATE 34

MAP SHOWING COPPER AND LEAD-ORE OCCURRENCES, BOLANGIR-PATNA DISTRICT, ORISSA.



GEOLOGICAL POTENTIAL OF THE KHETRI COPPR BELT, RAJASTHAN

By

M. K. Roy Chowdhury, S. P. Das Gupta, G.H.S.V. Prasad Rao, V. Venkatesh, A.S. Ramiengar, and W.K. Natarajan.
Geological Survey of India

(With Plate 35)

ABSTRACT

The Khetri copper belt extends over a distance of 80 km. from Singhana to Raghunathgarh and probably continues further to the south. On the southward extension of the belt lie such important prospects like Dhanaota, Satkui etc. along a prominent fault zone extending over a distance of about 20 km.

Some selected blocks within this belt were mapped in detail to study the features controlling mineralisation and to plan subsequent exploratory programme of work, Detailed maps of the Madhan-Kudan blocks formed the basis on which the Indian Bureau of Mines carried out exploratory work in its initial stage.

The rock types belonging to the Alwar and Ajabgarh series of the Delhi system have been thrown into a series of plunging folds which exhibit large scale culminations and depressions. In the northern part of the belt, mineralisation is restricted to basal part of the Ajabgarhs, whereas in the southern part it is higher up in the series. The major structural features of the area, which are also the chief controlling factors of the mineralisation represented mainly by pyrite, pyrrhotite and chalcopyrite, are the openings of the reverse faults and shear zones parallel to the strike of the formations or along the contacts of the different lithologic units. The direction and amount of the plunge of the ore shoots are probably controlled by the nature of those openings.

Based on the results of test drilling by the Geological Survey of India, it may be concluded that the Madhan-Kudan lodes extend northwards by at least two kilometres. Latest results of mapping and drilling indicate that Dhanaota-Satkui may also prove to be a promising one.

INTRODUCTION

Khetri was a centre of copper mining activity in the past, long before Hacket (1877) examined the region towards the end of the

nineteenth century. Prolific evidences of the ancient mining activity in Khetri (28°00' : 75°47') region are seen today in the form of old workings spread all over the belt, slag heaps of enormous size near Singhana (28°06' :75° 50') and dumps of mine waste near the portals of all the old stopes. The ancients had picked up the every possible surface clue of mineralisation in this region. The workings seem to have been closed down due to water trouble in the workings. About twelve years ago, the Geological Survey of India took up detailed investigation of the belt as part of a concerted drive towards proving additional resources of copper in the country.

Khetri copper belt lies in sheets 44P/12, 16 and 45 M/N.E. and S.W. Recent mapping has shown that the belt stretches over a distance of 80 km. from Singhana to Raghunathgarh (27°39' : 75°21') and probably even beyond, as one integrated copper belt with continuity of structural and geological features including copper mineralisation. On the southward extension of the belt lie important prospects like Dhanaota (27°45' : 75°30') Satkui (27°49' : 75°35'), etc., whose potentialities for copper production are currently being investigated by the Geological Survey of India.

DETAILS OF FIELD WORK

A total area of about 550 sq. km. covering parts of the Jhunjhunu and Sikar districts of Rajasthan, has been mapped on aerial photographs, the details of which have subsequently been transferred on base maps. The resultant regional geological map provides the essential perspective background of the geology of the area. The geological mapping was on the scale of 1 : 16,000 and 1 : 32,000 (approx.), and in some selected areas, on 1 : 1,200.

PREVIOUS WORK

Hacket (1877) was the first geologist to throw some light on the geology of the region. Heron (1917, 1923) brought out a generalised picture of the Khetri copper belt and also revised the classification of the rock formations of Rajasthan introduced by Hacket. The importance of Khetri as a future potential source of copper was stressed by

Dunn (1943). Deb (1948) published a short note under the title "Microscopic character of some copper-bearing metamorphic rocks from the Khetri mine area, Rajputana." Kerr Cross and Arogyaswamy (West, 1949, p. 77) worked on the area. Detailed work was undertaken by S/ Shri. D. K. Chandra in 1954-56, A. S. Ramiengar in 1954-56 and 1958-61, S. Aditya in 1955-56, V. Venkatesh in 1956-58; M. K. Roy Chowdhury in 1958-61; G. H. S. V. Prasada Rao in 1958-60; S. P. Das Gupta in 1956-61, and W. K. Natarajan in 1960-61 of Geological Survey of India. Summarised accounts of some of these investigations were published by B. C. Roy (1961-1962 a, b, c, d).

The Jaipur Mining Corporation conducted some prospecting operations in the area during 1944-46. Recently, the Atomic Energy Department has carried out some prospecting in the area for atomic minerals. The Indian Bureau of Mines has been carrying out drilling operations in the belt since 1957, and exploratory mining since 1959.

GEOLOGY

The rock types met with in the area may be grouped as under :—

(1) *Sedimentary metamorphites :*

- (a) Moderately metamorphosed pelites.
- (b) Quartzites.
- (c) Actinolite marble intercalated with calc-silicate rocks and amphibolite.

It may be mentioned that there are all gradations between the first two classes of rocks, which may be described as phyllitic quartzites and quartzitic phyllites.

(2) *Intrusive rocks.*

- (a) Amphibolite (having a relict sub-ophitic texture) found as intrusive into nearly all the rock types of group (1).
- (b) Granite and related pegmatite and quartz veins. This suite is younger than the above amphibolites.
- (c) Basic rocks of the latest phase of igneous activity represented by dykes, cutting across all other rocks of the region.

While retaining the broad classification by Heron into the Alwar and Ajabgarh series the rocks of the Delhi system here are subdivided further during the course of the present work. The Alwars are pre-

dominantly arenaceous, while the Ajabgarhs are argillaceous. The indications of shallow water deposition, like current bedding, ripple marks and graded bedding, so commonly met with in the Alwar rocks, are relatively rare in the Ajabgarhs. There is a narrow but distinct zone of transition having a widely varying mineralogical composition, between the two series. In that zone the proportion of the chlorite and biotite increases gradually from bottom to top. In some places, a basic rock consisting chiefly of anthophyllite and/or cummingtonite is developed at the contact between the two series.

The following generalised succession (Table—1) has been worked out with the aid of primary sedimentary features and other secondary structures :

Table—1

Intrusives (Post Delhi)		Blown sand, alluvium. Quartz veins, chert ankerite veins. Thin amphibolite dyke (original dolerite) Pegmatites and quartz veins. Granite gneiss, hornblende-granite. Pegmatitic granite, aplite etc. Amphibolites (metamorphosed basic igneous rocks).
DELHI system	Ajabgarh series	Marble. calc-gneiss, amphibolite and amphibole quartzite. Massive quartzites. Schists rich in chlorite, biotite, garnet, staurolite, kyanite, sillimanite and andalusite. Phyllites, carbonaceous phyllite, phyllitic quartzite. (Gradational contacts).
	Alwar Series	Actinolite marble, amphibolite and amphibole quartzite ; arkosic quartzites, quartzites and intercalated schists and phyllites.

METAMORPHISM

The general rock types in the area are phyllite, garnet-chlorite-quartz-schist, sillimanite-schist, kyanite-schist, staurolite-schist, chloritic quartzite, anthophyllite-quartzite, quartz-biotite schist, amphibole-quartzite, ferruginous quartzite, anthophyllite-cummingtonite rock, marble, calc gneiss and amphibolites. The highest grade of metamorphism, noted in the area, which is beyond the amphibolite facies, is encountered in the southern half of the belt. But in the northern half the mineral assemblages in the rocks indicate a grade of metamorphism that falls within the upper part of the amphibolite facies. The presence of of andalusite in some of the rocks of the northern half indicates that, in addition to the appropriate chemical composition of the sediments, they were also influenced by the thermal effects caused by the emplacement of intrusive bodies. Formation of felspathic schist and felspathic quartzite can be attributed to the metasomatic effect of felspathisation resulting from the intrusion of the granitic rocks.

That there has been extensive magnesia metasomatism in the area is evidenced by the presence of anthophyllite-cummingtonite bearing assemblages in the rock types like garnet-chlorite-quartz schist, chloritic quartzite and anthophyllite-quartzite, which are widely distributed in the northern half.

Retrograde metamorphism is evidenced by the sericitisation of andalusite and kyanite and chloritisation of garnet, biotite and hornblende. The shearing stresses and the ingression of hydrothermal solutions related to the mineralisation of the area have presumably provided an ideal environment for such retrogression.

STRUCTURE

The general strike of the formations varies between N.N.E.—S.S.W. and N.E.—S.W. with many local deviations. The dip usually varies from 60° west to nearly vertical. The prominent structural feature is a number of major plunging folds into which the formations have been thrown, usually exposing the Alwar rocks in their cores. The folds plunge towards either south-west or north-east with the axial

traces oriented generally in the N.E.—S.W. direction. The Babai, Jasrapura and Chapoli-Ponk anticlines show culminations, while the depression between the Babai and Chapoli-Ponk anticlines is not well exposed. The area has been subjected to intensive strike faulting, but there is not much of lateral shift of the beds. The major strike faults with considerable dip-slip, which are either parallel to the strike of the formations or are along the contacts between the different lithological units, especially between quartzite and phyllite, have provided the main channelways for the ore bearing solutions. Parallel to these faults are also a number of shear zones, the latter having been developed as a consequence of the former. These major strike faults had occurred during the later stages of the regional folding. There are also a number of transverse faults seen in the belt, of which only a few are mineralised.

MINERALISATION

Copper mineralisation in the region is generally restricted to a fairly well defined linear belt extending from Singhana in the north to Raghunathgarh in the south, through the Madhan-Kudan-Kolihan-Akwali ridges and also the Satkui-Dhanaota and Chirana (27°42′ : 75°25′) ridges. Poor sporadic mineralisation is also seen at places outside the belt (Pl. 35). The most important zones of concentration of mineralisation in the belt are located at Kudan (28°04′ : 75°47′), Madhan (28°04′ : 75°49′) and Kolihan (28°01′ : 75°44′).

Below are given the generalised guide lines used in search of mineralised localities in the area :—

Criteria for locating mineralised zones.

(a) Presence of lenticular limonitic and hematitic bands representing gossan, often with diagnostic boxwork structures.

(b) Shear zones accompanied by ferruginous stains. Sometimes shear zones may not have any gossan capping.

(c) Surfacial encrustations of secondary copper minerals, like malachite and azurite.

(d) Ancient mining and prospecting as indicated by old workings ; the intensity of work is determined by the number and depth of

old workings, nature and shape of old stopes and quantity and quality of debris left near the site of mining and slag heaps.

(e) The amounts of sulphides left over in the faces of the old workings.

Host Rocks.

There is no strict lithologic control of mineralisation in the area. But it appears that schists and phyllites are the most favourable host rocks, quartzite, phyllitic quartzite, and marble being next in importance.

In the Madhan-Kudan, Lakhan-Peeliwali and Masjid-Dumdumwali blocks, the predominant host rock is garnet-chlorite-quartz schist. In the same areas phyllite and anthophyllite quartzite form less important hosts. Again, in the ridges west of Khetri town, garnet-chlorite-quartz schist is prominently mineralised. But further west in the Kolihan block, andalusite-schist is primarily the country rock for mineralisation, even though there is a narrow mineralised band of garnet-chlorite-quartz schist. In the Akwali area, there are no surface indications of mineralisation; but from dumps near the portal of the Akwali mine it can be presumed that the host rock is andalusite-schist (altered to sericite). The black slate described by Heron probably represents this rock which is dark in appearance due to considerable amount of graphite. Further south in the Dhanaota and Satkui areas, all the mineralised rocks are not exposed. But recent drilling indicates that the host rocks are quartzite, phyllitic quartzite and phyllite or schist.

In the eastern part of Babai (27° 34′ : 75°45′) Paprona (27°56′ : - 75°48′), poor mineralisation is seen in several rock types like silicified schist, felspathic schist, pegmatite or pegmatite quartzite, marble and amphibolite.

Structural controls of mineralisation

The major structural feature of the area, which also constitutes the chief controlling factor of mineralisation, is a system of reverse faults with considerable throws along the dip. The faults are parallel to the strike of the formations or are located along the contacts betw-

een the various lithologic units. The faulting took place most probably during the later stages of the regional fold movements. There is also a system of pre-mineral shear zones, which are parallel to and developed as a consequence of the main faults. They have acted as important conduits for ore solutions. Within the shear zones, a set of sub-parallel fractures 0.35 m. to one metre apart occur in the main mineralised belt. Other sets of such fractures are either at right angles or oblique to the prominent set. The sub-parallel fractures of prominent set have curved branches at one or both ends forming thereby a 'horse tail' structure. Towards the end of the Lakhan-Peeliwali hills, one such unique 'horse tail' structure has been mapped. Generally, the individual shear zones are not continuous over a long distance, but they break up into disconnected '*en echelon*' segments. Shear zones, as seen in the stoped areas, show highly variable westerly dips ranging from 40° to 70°. The most favourable places for mineralisation are those where they lie parallel to the bedding or foliation planes. It may be added here that all shear zones are not mineralised, nor all of them filled in or replaced by vein quartz; also not all such replaced or filled-in zones have been mineralised.

The intersections of the shear zones with minor fractures and transverse faults or other less important shear zones also constitute the loci of ore formation. Quartz veins are commonly found in these intersecting zones and they preferably follow the fracture planes where movements have produced small openings.

In Akwali (27° 56′ : 75° 46′), as well as in Madhan, drag folds which are genetically related to faults form favourable sites for localisation of ore. Mineralisation at Suradi (27°55′ : 75°47′) near Babai and at Ponk (27°49′ : 75°38′) is confined to the nose of the folds, where there are shear zones parallel to the axial planes of the folds.

In some of the zones of intersection of the cross faults with the main reverse faults and the associated shear zones are found important ore bodies. Significant examples are the Madhan, Kudan, Lakhanwali and the Peeliwali mines. It is tentatively suggested that some of the ore-shoots in the region are of the nature of inclined bodies whose plunges are determined by the lines of intersection of the cross faults with

the strike faults and associated shear zones. It is, however, difficult to evaluate the importance of such intersections without more sub-surface data. There are also some cross-faults which are of a post-mineralisation period. Mineralisation also appears to have extended to some distance on either side of the zones of both the strike and the cross-faults, giving rise to irregular bulging shapes of the ore bodies. Brecciation is characteristic of the faults in the area near Saintala-ka-Dhani (28°57′ 75°50′) and Satkui.

Stratigraphic control

Stratigraphic control of mineralisation in the region is rather ill defined. In the northern part of the belt mineralisation is restricted to the basal part of the Ajabgarh series, whereas in the southern part it has gradually shifted higher up in the series. Even though mineralisation was confined to this series in the zone of faults or shearing, there has also been considerable diffusion of the ore-bearing solutions away from those zones in the form of disseminations.

Size and shape of ore bodies

The shapes of old workings afford valuable clues to the nature of ore bodies. Most of the old workings consist of vertical or inclined shafts that lead to deeper situated stopes. The stopes are generally lens shaped with many side digitations and their longitudinal axes plunge towards south-west or S. S. W., that is, parallel to the regional fold axes. This suggests that the ancient miners followed the ore-shoots. In working out the ore-bodies they have also not scooped out the whole, for on the inner surfaces of the stopes some lean ore can still be seen. The direction and amount of plunge of the individual ore-shoots depended on the nature of the movement along fault zones.

In the Dhanaota and Satkui areas, shear planes as seen in the old workings are usually filled in by limonitic material and these converge in either direction to form lensoid bodies. From this it may be presumed that the ore bodies also are lens shaped. However, in that area mineralisation appears to be concentrated at intersections of diff-

erent sets of faults. Such intersections plunge either to the north-east or south-west depending on the direction of dip of the cross-faults.

Mode of ore formation

In the main mineralised zone *i.e.*, northern half of the belt, sulphides have been filled in the fissures formed in the competent units like garnet-chlorite-quartzite as well as in the schistose rocks. But replacement has also played a considerable part in mineralisation, specially along the fracture zones of schists. Textural evidence suggests that the ore has replaced the favourable host rock. Also quite a good amount of silica has been introduced along with the mineralising solutions. Thus, most of the mineralised horizons even in the schistose rocks are rich in silica. In fact, the familiar stained quartz is an ubiquitous associate of mineralisation in the region. Disseminated ore, as also the mineralisation found in the carbonaceous phyllites etc., has resulted by filling of pore spaces and not by fissure filling or by replacement.

Mineralogy

The sulphides in the ore, which are pyrrhotite, pyrite, and chalcopyrite, in order of abundance, occur in the form of irregular masses or as discontinuous veins and stringers in the country rock. Outside the main mineralised zone they are also found in the form of disseminated grains. Such disseminations are common in amphibolite, anthophyllite-quartzite, marble etc. Earlier observers have reported the presence of some cobalt minerals like cobaltite and denaite in the Akwali mine. It is likely that some nickel is also associated with the minerals ; specially pyrrhotite may be nickeliferous. Sulphides of rare occurrence in the field are arsenopyrite, chalcocite and covellite.

There are several bands of magnetite in the mineralised zone. It has been seen in some cases that arsenopyrite predominates over pyrrhotite above the magnetite horizon but beyond this magnetite horizon pyrrhotite predominates over arsenopyrite. The high divalent iron and low magnesia in the magnetite analysed from a sample collected from Banawas mine area suggest that this magnetite was formed at an appreciable depth and at high temperature.

Secondary copper minerals obtained in the field include hydrous copper carbonates, malachite and azurite, and chrysocolla. Secondary minerals like chalcanthite and possibly brochantite are seen as fine needles in the old stopes.

The gangue minerals associated with the ore are chiefly quartz, chlorite, tourmaline, actinolite, anthophyllite, garnet, magnetite, calcite, ankerite and scapolite. The mineralogical assemblage together with the mode of occurrence thus indicates that the deposits may be classed under the mesothermal group of hydrothermal deposits.

Wall-rock alteration

It is very difficult to establish the nature of wall-rock alteration caused by the mineralising solutions in this area because of the retrograde metamorphism suffered by the rocks. Thus, chloritisation, which is seen extensively, may be due to either this retrograde effect or the wall-rock alteration ; the same is the case with biotitisation or sericitisation in the amphibolite and andalusite-biotite schist.

However, observations made on the hanging wall side of the old stopes indicate that an early phase of mineralisation did cause chloritisation and biotitisation. Also, the development of actinolite and sericite accompanied extensive silicification irregularly in different parts of the mineralised zones. Extensive iron-magnesia metasomatism in this region, represented by the presence of anthophyllite and cummingtonite rocks, preceded the copper mineralisation. Along the shear zones, biotitisation in amphibolite appears to be more common than in any other rocks. Extensive silicification is observed near Paprona.

Superposed on this hypogene alteration is also a supergene kaolinisation which extends down to a depth of 120 m. But nowhere in the whole field a zone of supergene sulphide enrichment is seen.

Description of the various blocks of the copper belt.

(1) *Northern half :* The northern end of the belt is seen on the eastern flank of the hills immediately west of Singhana. Although some gossan bands are clearly seen, they appear to be localised features.

The area between this hill and the Peeliwali (N.W. of Gotro) is covered by blown sand and soil. Drilling carried out in the intervening ground to test the continuity of the mineralised zones has yielded positive results and an account of the operations is given later in the paper. Within this intervening ground is also situated a prominent old working, now mostly filled up, known as Banwas mine (28°05′ : 75°49′). A test drill hole put down to intersect the lode beneath this mine has indicated encouraging possibilities. Thereafter, from Peeliwali mine (28°05′ : 75°48′) to Dumdumwali mine (28°04′ : 75°48′) and a little even further south, are exposed three or four prominent parallel minearlised shear zones, which are more or less continuous between those two mines. Within this stretch are the promising blocks of Lakhanwali (28°04′ : 75°48′), Ghatiwali, Kudan (28°04′ : 75°47′), Madhan and Masjidwali (28°04′ : 75°48′) and their southern extension. The total strike length covering those blocks in this area is about four kilometres.

The main important mineralisation is in garnet-chlorite-quartz schist and chlorite-quartzite. Throughout this region both the footwall and the hanging wall of the mineralised zone coincide with the faulted contacts between different lithologic units obtained there. The footwall concides with the contact between arkosic quartzite (Alwar) and the garnet-chlorite-schist (Ajabgarh) ; while the hanging wall is at the contact between the garnet-chlorite schist and the phyllite. These faulted contact horizons are comparatively more mineralised than the central part of the ore zone. The faults at the contacts have obviously provided the convenient channel ways for the mineralising, solutions. The total width of the mineralised zone in this section varies, but it is widest near the Kudan mine, being 200 to 250 m. across. The set of sub-parallel fractures constituting the shear zones are oriented parallel to the strike of the faults, which are themselves generally parallel to the strike of the formations. The shear zones have a westerly dip ranging in amount from 60° to vertical. Within these blocks several units of 'horse tail' structure related to the shear zones are also prominently noticed.

A few geochemical traverses run across the hills of Kudan-Madhan yielded results confirming that the copper values are higher at the fracture and fault zones.

Next in importance to the Madhan-Kudan block are the Kolihan group of mines, which are situated on the high hills, west of Khetri. The schistose host rocks here contain garnet, chlorite, andalusite, sericite, etc. The mineralised zone in this part of the belt extends over a strike length of about 1.5 km. Here again the contact between schist-phyllite and the hard compact quartzite is faulted and the mineralisation is confined to the associated shear zones. In this locality the horizon of mineralisation is not at the base of the Ajabgarhs, but is higher up. But, at a place about 750 m. south-east of Kolihan, there is another group of old workings, where the mineralised horizon is at the contact of the Alwar quartzites and the Ajabgarh schists. This zone has a lateral extension of about 500 m. Proceeding further south along the belt, it is only near Akwali mine that evidences of conspicuous mineralisation are seen.

The surface manifestation of mineralisation is rather poor, and it might not have attracted much attention but for the important stopes and old workings present there. Akwali is located at about five kilometres N.N.W. of Babai. The mineralisation is mainly in the phyllite—schist and also locally in the amphibolites. It appears that the contact between the phyllite-schist and the amphibolite is faulted. The accompanyiny shear zones and the faults associated with the folds are mineralised. The mineralised zone extends over a distance of 1.5 km. towards the south of Akwali. Evidence for northern continuation is not very distinct. The stope of the Akwali mine is several hundred metres in length, but its width is narrow at both ends. Quartz-ankerite veins in the amphibolite have been prospected by ancient miners. Anthophyllite-cummingtonite quartzites and schists occur at the contact between the Alwar and the Ajabgarh series; but the mineralised zone lies about 300 m. west of the contact. This area lies in a comparatively inaccessible portion of the belt and is yet to be explored by modern methods.

Besides the three notable localities described above, there are also in the northern half of the copper belt some other minor occurrences. They are situated south-east of Khetri, near Usraka Dhani (27°59′ : 75°49′), Chirana, etc.

(2) *Southern half:* The southern half of the Khetri copper belt extends up to Raghunathgarh (27°39′: 75°21′) and is in fact structurally and geologically continuous with the northern half of the belt. The southern half comprise a poorly developed interior region with only fair weather tracks over the rugged terrain.

In this part of the belt there are two important blocks namely, Dhanaota and Satkui apart from other minor ones. At both the places there are many old vertical shafts which probably lead to deeper stopes, indicating extensive mining activity in the past. There is a prominent fault zone running through both the blocks and extending over a distance of 20 km. It is possible that it continues further in either direction under the covered terrain.

Close to Dhanaota, there is a group of old workings known as Baun Kui, the term meaning fifty two wells. All these are situated on a very thick gossan zone. The rocks have been completely leached out leaving behind a thick mass of limonite and silica with some pyrolusite intermixed. The whole width of the jasperoid gossan may not represent the true width of the mineralisation beneath, as there is a likelihood of the gossan cap having a mushroom shape. The gossan zone has an extension of about 1.6 km. and a width varying from 150 m to 250 m. Another striking feature of the mineralisation is that the zone of oxidation is unusually deep (about 150 m.) Phyllite and phyllitic quartzite are the main host rocks of mineralisation. The fault which is at the contact of the phyllite and quartzite, with the accompanying shear zones, has been mineralised. The shear planes are arranged sub-vertically in *en echelon* pattern, with a small lateral shift between any two of them. Each individual plane may have a vertical extension of 16 to 17 m. Cross faults are also common in this locality and they appear to have played a prominent role in the mineralisation of the area, acting as conduits.

In the Satkui area, which is situated about four kilometres west of Gurha (27°49′ : 75°38′), the most pronounced structural feature controlling the mineralisation is a fault zone striking N.60°E.—S.60°W. and dipping 60° northerly. The zone lies at the contact of phyllite and schist on the western solpe of the quartzite ridge. The schist and phyllite are, however, not exposed in the area but they have been met with in the drill hole put down.

The old shafts are very deep, some of them going vertically down to 70 m. or more. Some of the faces exposed by cutting are also very high. The width of the gossan zone ranges from 15 to 35 m. and its strike length is about 750 m. The same has a southward continuation up to Chirana through Girawari (27°45′ : 75°31′) or Tinkui and Dhanaota, over a distance of about 20 km.

Besides the above two blocks, a number of other gossan areas (limonite zones) have also been noticed. There are at least two fairly wide quartz-limonite zones in the area between Saladipura (27°38′ : 75°31′) and Seoli (27°38′ : 75°27′). The more prominent one, which occurs at about 1.6 km. north-west of Saladipura, follows the sheared contact of a folded amphibolite with quartzose schist or phyllite. It is difficult to assess at present the significance of these limonite zones. But, if ultimately the Satkui and Dhanaota blocks turn out to be of economic importance, the above prospects also may be investigated further.

Results of test drilling carried out by the Geological Survey of India in the Khetri Copper belt.

(1) *Babai-Paprona block :* In the area east of the Babai-Paprona road, some evidences of minor mineralisation are obtained along the fault or shear zones at the various contacts between schists silicified schists or carbonaceous schists and marble.

Geophysical exploration in the area indicated some apparently promising anomaly zones. In order to determine the causative factors yielding such geophysical results, test drilling was undertaken. In all, six inclined shallow drill holes were put down. The results obtained were not encouraging, as they revealed only poor and sparse sulphide mineralisation combined with the presence of graphite, the latter presumably being the main cause of the anomalies.

(2) *Dhanaota block :* So far, three boreholes have been put down in the Dhanaota block. The main feature of the results obtained was that the holes appeared to be still in the zone of oxidation at the depths at which they intersected the mineralisation zones. A few specks of sulphides like pyrite and chalcopyrite were, however, noticed. They were presumably relicts which have escaped oxidation due

to their being in the unsheared or partially sheared wall rocks. Deeper holes are, therefore, being planned in order to intersect the main unaltered zone of sulphides.

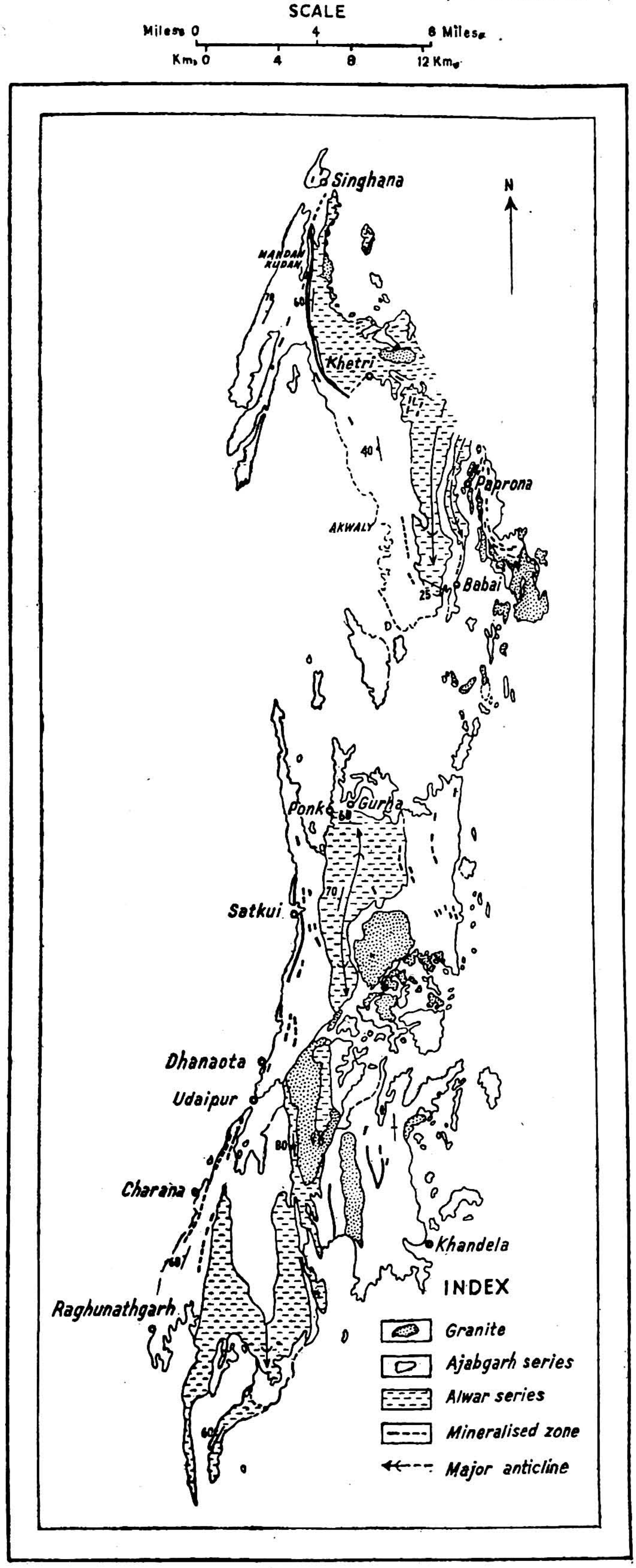
(3) *Satkui block :* Examination of the cores recovered (core recovery was poor because of the hole passing through altered and crushed zones) indicates encouraging possibilities. The mineralised zone was touched at the inclined depth (inclination being 60°) of 105 m. in phyllitic and schistose rocks. The faulted zone of contact between phyllite and quartzite was first encountered at the inclined depth of 138 m. and it extended down to 162 m. Thereafter, the mineralisation was sparse. Pyrite and chalcopyrite were the important ore minerals, while pyrrhotite was found in subordinate amounts.

Sludge samples, corresponding to the runs from which core samples were drawn, were also analysed ; these are from the depths of 138.77 to 141.82 m. (sample no. 1), 148.23 to 151.28 m. (sample no. 4) and 151.28 to 153.41 m. (sample no. 5). The copper percentage in core and sludge for sample nos. 1, 4 and 5 are 6.75 and 1.74 ; 3.93 and 0.87 and 5.88 and 0.93 respectively. The proportion of copper content in the sludge samples to that in the corresponding core samples from the depths mentioned above are 1:4, 1:4.5 and 1:6.25 (approx.) respectively. Though the values are high, they appear to be rather erratic. Until more data from a deeper hole with satisfactory core recovery are available, a proper assessment of the ore body cannot be made. Hence, it is suggested that a deeper hole may be put down, ensuring maximum core recovery.

(4) *Banwas-Singhana block:* The mineralisation in the Madhan-Kudan and Lakhan-Peeliwali blocks, terminates abruptly after a few hundred metres north of the Peeliwali hill. With a view to testing the continuity of the mineralised zones in the intervening covered ground, exploratory geophysical survey was carried out in the first instance and the results indicated a continuity. Drilling carried out in the area confirmed the northword extension of the mineralised zones over a distance of about two kilometres from the northern tip of the Peeliwali hill. In all six drill holes were put down in the area and of these, two yielded very encouraging results. In borehole No.KBH 7, located near the Banwas mine an ore-zone was met with between the inclined depths (inclination being 45°) of 90.7 m. and 94.4 m. This width of

PLATE 35

GEOLOGICAL MAP OF THE KHETRI COPPER BELT, JHUNJHUNU AND SIKAR DISTRICTS, RAJASTHAN



3.7 m. gave an average assay value of 1.63 per cent copper of which the top 1.75 m. width showed a value of 2.13 per cent. The other important borehole, KBH 9, which was drilled to intersect the lode beneath the Banwas mine, showed unevenly distributed mineralisation between the inclined depths (inclination being 45°) of 33 and 116.6 m. In between these depths, five zones totalling a width (inclined) of about six meters were met with and the copper content of these zones ranges from 1.16 to 2.56 per cent.

In the absence of more drilling data and in view of the erratic distribution of the ore-zones, no attempt has been made to calculate the probable reserve of this area.

CONCLUSIONS

Mineralisation in the Khetri copper belt is primarily controlled by shear zones produced as a result of large scale reverse faulting which is conspicuous in the area. Garnet-chlorite-quartz schist, chloritic quartzite, phyllite and quartzite are the important host rocks. The region between Singhana and Raghunathgarh constitutes one integrated copper belt with uniform structural and geological features.

The data so far obtained (1961) by the Geological Survey of India by mapping and drilling in the Khetri copper belt indicate that although the quality of ore is of sub-marginal grade, the reserve may prove to be of large magnitude. It is recommended that all the various blocks listed in this paper may be explored in detail according to a priority worked out on the basis of these results.

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GEOLOGY AND CONTROLS OF ORE MINERALISATION OF SOME OF THE MINE AREAS IN ALWAR, JAIPUR AND SIKAR DISTRICTS, RAJASTHAN.

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(With Plates 36-43)

ABSTRACT

The paper describes the geology of Nagel (Pratapgarh) Jodhawas, Mothoka, Kalajoda, Matasula, Bhagoni, Agar and Nalladeshwar mine areas. The probable structural and lithological controls of ore mineralisation in these mine areas have also been discussed. Despite the absence of surface indications of ore in most of these mine areas, there are sufficient geological evidences for planning exploratory programme in the areas investigated. Initial exploration should, therefore, be carried out to confirm the controls and to establish the nature and extent of mineralisation.

In the Nagel mine (Pratapgarh) area, recent drilling has proved the existence of a north-south trending mineralised fault zone. The main problems of drilling in this area are the unusually deep old workings and zone of leaching and also drilling from the footwall side of the fault zone. Deeper drilling will provide information regarding the primary zone. In the Jodhawas mine area the main control of mineralisation is possibly both stratigraphic and structural. In the Mothoka, Kalajoda, Bhagoni and Matasula mine areas, the main controls of mineralisation are the faults.

INTRODUCTION

There are a large number of abandoned mines in the Alwar, Jaipur and Sikar districts, Rajasthan and the Geological Survey of India has taken up detailed investigation of these ancient mine areas

to assess their future prospects. The work was commenced in 1953 and is being continued since then. Initially, Shri B. Srikantan started the investigation and was later joined by the other authors. The mine areas dealt with are Nagel (Pratapgarh), Jodhawas, Mothoka, Kala-joda, Matasula, Bhagoni, Nalladeshwar and Agar.

The investigation in the areas consisted of large scale geological mapping of mine areas with plane table and telescopic alidade, mapping of underground mine workings, mapping of the adjoining areas on large scale air photographs and geochemical prospecting.

All these mine areas are connected by fair weather roads, to the Delhi-Jaipur National Highway between Alwar and Shahpura.

GENERAL GEOLOGY

The mine areas are located in the Pre-Cambrian rock formations which have been classified by A. M. Heron, (1917) as follows—

Post—Delhi		Quartz veins, aplites and Pegmatites
		Granite
		Metadolerite
Delhi System	Ajabgarh Series	Schists, phyllites, marble and quartzites
	Hornstone Breccia	Brecciated quartzite
	Kushalgarh limestone	Marble
	Alwar Series	Quartzite, gritty quartzite, schists and phyllites
—Unconformity—		
Pre-Delhi	Raialo series	
	Aravalli system	

The mine areas are widely separated and until the intervening area is geologically mapped, a general correlation of the rocks cannot be made. The rock formations in the different mine areas are, however, assigned the same names as given by Heron, conforming only to lithological similarities.

DELHI SYSTEM

Alwar Series: The rocks of the Alwar series are predominently arenaceous and consist mainly of quartzite, often gritty and at times even conglomeratic, along with schists and phyllites. The quartzite is compact, well-jointed, pink to white in colour and sporadically arkosic. Cross-bedding is seen very clearly in these rocks; it is very helpful in deciphering the stratigraphic tops. The schists consist of sericite and biotite and show at places, development of garnet or andalusite. Phyllite is usually carbonaceous. Bands of massive quartzites occur interbedded with schists and phyllites.

Kushalgarh limestone; The Kushalgarh limestone is a highly banded rock, developed locally in the region and is considered by Heron to be a transitional series between the Alwar and Ajabgarh series.

Hornstone breccia : The hornstone breccia, in general, consists of angular fragments of hard quartzite in a siliceous cherty matrix, quite commonly ferruginous. In some places the breccia can be traced to grade into a massive quartzite through highly fractured zones. While it is described and assigned a position as one unit by Heron (1917), it is actually divisible into two *viz.* (i) a sedimentary or clastic breccia which closely follows the contacts and bedding in Ajabgarh, Kushalgarh and Alwar series and (ii) a tectonic breccia traversing across all the rock formations and undoubtedly related to later movements, either faulting or folding.

Ajabgarh series : The Ajabgarh series consists essentially of phyllites, frequently carbonaceous, interbedded with quartzite and marble. The marble is also well banded and is similar to the Kushalgarh limestone. Along certain zones it shows a marked development of calc-silicates such as actinolite and tremolite.

Post-Delhi formations—Metadolerite: The metadolerite is intrusive into the rocks of the Delhi system but is involved in the later stages of folding. It is normally a melanocratic, coarse to medium-grained, well-jointed massive rock consisting mainly of hornblende, biotite and quartz with minor augite and relict textures. Along certain zones, however, as near faults and intensive folds, it is highly foliated and is

an amphibole-schist. The metadolerite is most common in the Alwar rock formations and probably most of the intrusion took place during this period.

Granites : The granite is intrusive into all the rock formations of the area and occurs as small stocks, cutting across the other rock formations and fold axes. It is a medium to coarse-grained, leucocratic rock, consisting mainly of quartz, microcline and biotite with minor hornblende. There is usually a persistent zone of contact alteration in country rocks—the schists, quartzites and metadolerite around the granite bodies, the resulting rock consisting of hornblende, quartz, augite, felspar and epidote with subordinate zircon, rutile, apatite, sphene and magnetite.

Thin veins of pegmatite, aplite and quartz are seen in most of the rock types but quartz veins are the most common. The quartz is milky white, opaque and some veins bear copper minerals, calcite and baryte.

Structure

This region forms a part of the Pre-Cambrian terrain of Rajasthan in which the rocks are highly folded and faulted and have undergone more than one deformation.

The general trend of the major folds is northerly and these plunge northwards at moderate angles indicated by a large number of northerly plunging minor folds. Small-scale folds plunging in the opposite direction, doubly plunging minor folds with twisted axes, seen in the banded Kushalgarh limestone, convergence of beds on both sides along the axial planes and two directions of foliations suggest a later cross folding. While the unconformity between the Delhi and the Vindhyan systems represents a major period of deformation, Delhi system itself represents probably more than one period.

There are a large number of faults, some with considerable displacement, the most dominant of which strikes north-south and have steep dips. There is intense brecciation along some of the faults. In one area a very sharp structural discordance is interpreted to be the

result of a thrust fault and there may be a few oblique ones also. Faults are also found to cut across the intrusive granite. The major northerly trending faults are the most important structural traps for epigenetic ore mineralisation in the region.

HISTORY OF MINING

This part of Rajasthan must have been an important mining and smelting centre in historical times as can be made out from extensive old mine workings and slag dumps found in many areas. This industry appears to have been stopped about the middle of 19th century. Some of the reasons for closing down these mines might have been the depth of the workings, to which they had reached, the inability to pump out water since these mines reached below the water-table and thinning out of rich ore shoots. The only instance of active copper mining and smelting, though on a small scale, noted in the later part of the 19th century was at Dariba (District Gazetteer of Alwar, 1880).

Surface indications of the ore mined are almost totally absent but analyses of slag, waste rock and small specks of sulphides noticed in the waste rock indicate the main ore to have been of copper. In one or two instances, as at Bairath, there are very extensive slag dumps but there are no old workings of any significance nearby; this indicates that the ore was brought from several mines at distant places to these smelting centres.

GEOLOCY OF THE MINE AREAS

1. Nagel (Pratapgarh) (Pl. 36)

The mines are located near the village of Nagel, south-west of Pratapgarh and are reached from Thanaghazi on the National Highway.

Rock formations : The rock formations of the area, classified by Heron as Alwar series of the Delhi system, consist of quartzite and schists with minor intrusions of metadolerite. These rocks can be grouped into (i) a schist group consisting of quartz-chlorite schist, biotite-schist, andalusite-biotite schist and fissile quartzite, occupying the valleys and (ii) massive quartzite forming the ridges.

The schists are not exposed in the mine area, except for an isolated outcrop, seen north of the village Nagel, where it consists of biotite, chlorite and quartz. The schist, as encountered in the drill holes, is a very compact but foliated rock consisting mainly of quartz and sericite, with thin bands of biotite-schist, which shows rare development of scapolite and kaolinised felspar. Near its contact with the massive quartzite, the schist grades from quartz-sericite schist to biotite-schist. A trench put down in the area shows biotite-schist containing porphyroblasts of scapolite up to 4 mm. in diameter. The schist also contains bands of massive quartzite in which the bedding and cross-bedding can be made out clearly. The quartzite is occasionally conglomeratic.

The quartzite is a light coloured, massive, compact, well jointed rock, occurring along the main ridge of the mine area. Bedding is clear in this rock, though the absence of cross-bedding makes it difficult to decipher the stratigraphic tops. It consists essentially of medium grained quartz and minor amounts of sericite and magnetite. Felspar is rare. The joints in the rock are filled with ferruginous matter. Along certain zones, specially near its contact with the schist, the quartzite is highly brecciated, the resulting rock consisting of fragments of quartzite embedded in a siliceous and ferruginous matrix. Drilling has shown that it also contains small specks of native copper, associated with probable chalcocite and mostly secondary iron-ore.

Metadolerite is a massive, compact, coarse grained rock consisting of hornblende, felspar, quartz, magnetite and relict augite. A rock met with in one of the drill holes is seen to consist mainly of hornblende and plagioclase.

Structure : The general trend of the strike of the rocks in the area is N.N.E.—S.S.W. The schist and the interbedded quartzite bands dip steeply to the west or to the east. The massive quartzite of the ridge dips westward at low angles of 30° to 55°. Foliation follows the bedding planes. Jointing is common, specially in the quartzite, the general directions being N.75°E.—S.75°W. or N.75°W.—S.75°E. with moderate dips towards north or south. The joint surfaces are smooth.

The main structural feature of the mine area is the fault trending N.25°E.—S.25°W. at the contact of schist and the quartzite. The

quartzite is very highly brecciated near the fault and the schist has developed porphyroblasts of scapolite. The contact between the schist and quartzite dips at 70° towards east. This fault is the main control of mineralisation.

Old workings : The old mine workings consist of a large number of narrow shafts located along the western flanks of the ridge, east of Nagel village, traceable for over 6.4 km. in N.25°E. direction. The shafts are from 6.1 to 122 m. in depth. While the main alignment of the shafts is along the regional strike (N.25°E.—S.25°W.) there are some shafts which are aligned in an east-west direction. Most of the shaft bottoms were filled up with mine rubble.

The mine debris consists of limonitic brecciated quartzite and quartz-chlorite schist or quartz-biotite schist. Sulphides are seen as very small specks. Secondary minerals of copper are rare. There is considerable amount of slag in the mine area and analysis of the slag and the mine debris shows copper up to 2,500 p.p.m,

A number of workings, consisting of deep shafts about 800 m. east of this zone has also been traced for a length of about 1.5 km. ; these are also fringed with mine debris and slag heaps.

Mineralisation : Surface indications of the ore mineralisation are very sparse in the area. The debris shows only small specks of sulphide minerals but contains large proportions of hematitic material which fills the fractures and joints in the quartzite. Drilling has shown native copper and minor sulphide specks in the zone.

Controls of mineralisation : The study of the old workings suggests a very dominant structural control of mineralisation, namely the fault trending N.25°E.—S.25°W.and dipping eastwards at 45° to 70°. A lithological control is also suggested by the mine debris which consists of the porphyroblastic schist and a highly brecciated quartzite.

The main problem of carrying out prospecting by drilling in the area is that the approach has to be made from the footwall side of the zone which varies in dip from 45° to 70° towards east. The hanging wall side is topographically very difficult of access and consists of the entire thickness of massive quartzite. Another problem is the unexpected depth of the workings which extend down to 135 m. from the surface.

Drilling has shown that mineralisation and also the zone of secondary enrichment extend to a depth of about 225 m. from the surface and that the primary ore can be intersected only at much greater depths. Deeper drilling is planned to intersect the zone at about 420 m. from the surface.

2. **Jodhawas (Pl. 37)**

The area is located about half a mile east of Jodhawas and is reached from Thanaghazi on the National Highway.

Rock formations : According to Heron the rock met with in this mine area is principally a marble of Ajabgarh series of the Delhi system. It is generally arenaceous and shows variations from a compact, massive, light coloured rock to a dark coloured, highly banded one, containing rapidly alternating argillaceous bands and laminations. These variations, however, grade into each other at very short distances. A few bands are schistose and contain tremolite and actinolite. In thin sections the marble shows anehedral crystals of calcite, dolomite and quartz with accessory magnetite. Cross-bedding is very common and provides conclusive evidence for discerning the tops and bottoms of the beds. Except for the thin bands in which the marble is siliceous and contains convolute structures, the marble does not provide any marker horizons to decipher the structure. A few thin veins of quartz are also present.

Structure : The structural evidence shows that there are at least two major folds trending N. E.—S.W., an anticline in the west and a syncline in the east. Probably another syncline and an anticline are present between these folds but the absence of a marker horizon for the whole area makes it difficult to trace them.

In the major anticline, the beds dip westwards at steep angles in both the limbs (with normal tops in the western limb and reversed top in the eastern limb) and show an overturned asymmetrical anticline with the axial plane dipping about 70° westwards. The anticline plunges 35° towards N. 30° E.

In the syncline the beds dip towards the axis at different an-

gles with tops of beds pointing towards the axis. The syncline is a normal open asymmetrical fold with the axial plane dipping steeply westward at 85°. The sharp convergence of the bedding in the two limbs suggests it to be *chevron* type of fold. This syncline also plunges northwards.

While the plunges of a large number of drag folds conform to the general plunges of the folds, some minor folds seen along the limbs of the anticline and syncline, plunge in the opposite direction, *viz*. in S. 30°—40° W. at 30° to 40°, often showing opposite movements in the limbs of the folds. Minor drag folds plunging in both the directions and with twisted axes are commonly seen in both the limbs of anticline and syncline. The syncline, in addition, shows convergence of beds and bedding in the northern part. These structural features indicate the major folds to be doubly plunging folds. The double plunge probably is the result of cross folding. It has not been possible to follow the axis of the cross fold.

The bedding, the relatively undistorted cross-bedding and other primary sedimentary features and the indistinct foliation in the marble suggest that the folds are flexure folds and not shear folds.

Only a few faults are seen in thc area but they are minor. They strike N. 25° to 50° E.—S. 25° to 50° W. and trend obliquely to the strike of bedding. There may be a fault along the axial plane of the syncline.

Foliation is indistinct but the marble is very well jointed. The joints can be grouped into three dominant sets—N. 60° W.—S.60° E.; N. 30° W.—S. 30° E. and N. 30° E.—S.30° W. all dipping at 60° and above. The general appearance of the smooth joint surfaces is suggestive of their being shear joints.

Old workings : The old workings consist mainly of trenches and to a less extent of inclined shafts and open pits. In general, the walls are in solid rock and follow the features of the rock formations. The trenches vary from 15 to 76 m. in length, 2.5 to 9 m. in width and 3 to 23 m. in depth. The workings follow certain beds in the marble. The mine rubble consists of massive marble with specks of sulphides

minerals. A small amount of slag is also present near the village of Jodhawas. The workings can be grouped into six zones, having a general N. E.—S. W. trend.

Mineralisation : No distinct lode can be seen in any of these workings and the wall rock shows only minor specks of sulphides. The rubble shows irregular stringers and specks of chalcopyrite, chalcocite and bornite. The mine rubble also shows some barytes. There is no leaching or oxidation as sulphides occur within a few centimetres from the surface. Secondary minerals such as malachite are rare.

Controls of mineralisation : The old workings are located along certain beds in the marble indicating that possibly they are the only beds which are mineralised, either because they acted as (i) the most favourable rocks for replacement due to epigenetic mineralisation which followed the axial planes of folds and probable faults or (ii) the stratigraphic horizons which contained original constituents of sulphides which were later activated and concentrated (C. L. Knight, 1957).

Stratigraphic control is indicated by the mineralised zones being located only along certain beds in the marble. It has, however, not been possible to trace them separately or to establish that the same beds are present in all the mineralised zones, due to lack of suitable marker horizons. The only exception is in the eastern part where the workings are seen in a band of marble with convolute structures and are located in both limbs of a syncline.

3. Mothoka (Pl. 38)

The mines are situated on a low hill about 800 m. S.S.W. of Mothoka village. They are approached by a road from Shahpura on the National Highway, through Kotputli.

Rock formations : The rock formations of the Mothoka mine area are classified by Heron as belonging to the Ajabgarh series of the Delhi system.

The rock formations are highly folded and faulted and the normal contacts between the rock types or the evidences of tops and bottoms within the same rock type are not seen anywhere. The rocks are now divided into two groups shown below, based on the marked structural discordance between the western and eastern parts, caused by a thrust fault. Stratigraphic positions of the rocks remain to be confirmed by geological mapping of the adjoining areas.

Aplite and quartz veins

	Main (western) Group	Thrust block (eastern) Group
Ajabgarh—series (DELHI SYSTEM)	Schists (sericite-quartz schist, quartz-sericite schist, quartz-biotite–sericite schist)	Schists (sericite-quartz-schist, quartz-sericite-biotite schist, sericitic quartzite, calcareous quartz-sericite schist)
	Carbonaceous phyllites	Felspathic quartz-biotite schist
	Massive quartzite, brecciated at places.	Carbonaceous phyllites and interbedded dark siliceous quartzite.
		Calcareous quartzite.
		Arenaceous marble.

Western group : The schistose group shows variations which, however, cannot be marked separately on the map. The carbonaceous phyllite is generally dark coloured and is highly ferruginous along fault zones giving rise to gossan-like appearance. The massive quartzite forms the highest part of the area and is a compact, well jointed rock. Along faults it is highly brecciated, the breccia consisting of fragments of quartzite in a siliceous matrix.

Thrust block (eastern) group : The main rock in this block is the schist which shows great variations and felspathic at places, containing microcline. The phyllite is carbonaceous and also shows ferruginous filling. The schist, calcareous quartzite and arenaceous marble

show intergrading and interbedding relationship in the northern part. Secondary calcite is also common.

Thin veins of aplite consisting of micro-crystalline quartz and perthitic felspar are seen at some places. Quartz veins are rare in the area.

Structure : The main structural feature of the area is a very marked discordance between the eastern and the western blocks separated along the crest of a ridge, and to a lesser extent in the rock formations. In the western block, the rocks are not folded and trend roughly N. 10° E.—S. 10° W. dipping at steep angles to the west. Bedding is indistinct. In the eastern block, the rocks are highly folded and trend across the strike of the rocks of the western block. This is best seen in the northern part of the area where the rocks are highly crushed and occur as lenses in one another. Minor folds are common; they plunge northwards at 25° to 80° with inclined axial planes. A recumbent anticline is also seen in the southern part of this block. An abrupt discordance can not be explained by simple faulting and it is presumed that the rocks of the eastern block have been thrust along a fault over the rocks of the western block.

Two directions of foliation can be made out in the schist. The prominent one follows the strike of the rock formations and dips at steep angles. The second one varies between N. 30°W.—S. 30°E. and N. 60°W.—S. 60°E. in strike and dips at low angles of 30° to 40° westwards or southwards. The main joint direction is approximately N. 60°W.—S. 60°E. with steep dips.

Traversing through both the blocks, there is a major north-south trending fault, producing a zone characterised by brecciation of the quartzite, shearing in the carbonaceous phyllites with ferruginous fillings (probably gossan) and displacing the contacts between the rocks of the eastern and western blocks in the northern part of the area. This major fault zone is about 20 m. wide and can be traced for over 350 m. in length. The fault is dipping steeply towards west and the minor rolls seen on the rock surfaces plunge at 20° to north, indicating nearly vertical movement on the fault zone. The fault is post-thrust, offsetting the rock contacts of the thrust block in

the northern part. There are a large number of minor faults, either crossing or terminating at the major fault. These are indicated by zones of brecciation in the quartzite. Other minor faults trending north-south have also been noticed.

Old workings : The old workings consist of a large number of small diameter pits and vertical and inclined shafts. Most of them are filled up and do not lead to stopes. The workings can be classified as those located (i) along the main fault zone, which are nearly vertical or inclined steeply and (ii) in the eastern block ; these are shallow and inclined or vertical following the plunging folds or minor faults. The mine debris from these workings does not indicate extensive mining. Except for some scattered slag near Mothoka village, no slag dumps are noticed in the area. During recent years, an adit about 59 m. long has been driven into the hill from the base.

Mineralisation : Most of the shafts do not provide any information on the nature of ore that was mined. Some of the shafts show a highly brecciated, ferruginous carbonaceous phyllite which looks like a gossan. In the adit there is only one rock type—the biotite-schist which shows a large number of joints and a thin mylonitised zone. The adit has not pierced through the main zone and no sulphide minerals were seen in the waste rock.

Primary sulphides are not seen either in the adit or in the debris from the other old workings. Minor sulphide specks are seen in the highly crushed quartzite in the northern part of the area.

Controls of mineralisation : The main control of mineralisation is the fault zone which is about 20 m. wide and strikes N. 10°E.—S. 10°W. and dips steeply westwards. The rocks in the zone show gossan like features. The secondary controls of mineralisation are the fold axes and minor faults seen in the southern part of the area.

4. Kalajoda (Pl.39)

The Kalajoda area is located on a ridge about three kilometres W.S.W. of Bairath town on the National Highway.

Rock formations : The rock formations of the area consist of quartzite and schist, classified by Heron as Alwar series, metadolerite and granite.

The quartzite is a light coloured, massive, well jointed rock with indistinct bedding, consisting mainly of quartz with subordinate mica, which increases in the slightly more schistose quartzite, and magnetite. Along structural breaks and faults, the quartzite is highly brecciated, the breccia consisting of angular fragments of quartzite cemented in cherty siliceous and commonly ferruginous matrix.

The schist is a well foliated rock consisting mainly of biotite, accessory quartz and microcline and with large round grains of plagioclase developing across the foliation.

The metadolerite is a massive, well-jointed rock consisting of hornblende with relict augite, quartz, plagioclase and magnetite, exhibiting a sub-ophitic texture. Along the fault zone it is highly foliated, the resulting rock being an amphibole-schist. The metadolerite shows an intrusive relation to the sedimentary rocks.

The granite is coarse grained, well jointed and consists essentially of quartz, microcline and plagioclase, with minor biotite and accessory magnetite and tourmaline and exhibits a hypidiomorphic texture. Along fault zones it is highly brecciated, the breccia consisting of pieces of granite and vein quartz embedded in a siliceous matrix which contains large round grains of microcline. It has a cross cutting relation to the schist, quartzite and metadolerite.

Vein quartz occurs in irregular, discontinuous veins. They are usually brecciated with ferruginous fillings.

Structure : The general strike of the quartzite and schist is N.50°W.—S.50°E. except for some variations caused by minor folds. Minor folds plunging south-west and south-east at 45° are seen in the schist.

The main structural feature of the area is a fault zone

trending N.70°W.—S.70°E. which can be traced for about 900 m. It is indicated by a 30 m. wide zone of breccia, quartzitic in the south and felspathic in the north. It cuts across all the rock formations, offsetting very prominently the quartzite-granite contact to the north. It is vertical or steeply dipping towards west. It is a normal fault, the western part being the down-throw side and has a horizontal offset of about 240 m.

The brecciated zones in the granite are also probably located along fault zones. Cross faults, which offset the breccia zones in the granite, are also present. The main fault is post-granite in age, while the strike faults are probably older.

Old workings : The old workings consist mainly of small diameter shafts, 4.5 to 30.5 m. in depth, vertical or inclined, and shallow pits. The workings are located mainly within the brecciated zones in the southern part of the area and show mine debris, consisting of breccia, schist and quartzite. Most of the shafts are filled up at the bottom. An inclined shallow shaft led into a minor stope in which a 37 to 150 mm. wide kaolinised zone with malachite stains, striking N.10°W.—S.10°E. and dipping 50° towards west, is noticed. The stope is deeper in the southern part and the wall rock is quartzite and breccia. In the northern part two shafts open into a stope at 15 m. from the surface, the stope extending for 45.5 m. along N.8°W.—S.8°E. direction and dipping at 50°—60° eastwards. The workings are located in the brecciated zone of granite. The shear zone in the shafts contains ferruginous fillings with breccia, dipping eastwards. No sulphide mineralisation is seen.

Another set of workings of shallow inclined pits is found in the quartzite. Minor specks of chalcopyrite are seen in the rubble which contains ferruginous breccia. Two shallow pits are located in the granite which contains a large number of quartz veins. Malachite stains are very common.

The mine waste in the southern part of the area does not indicate that a great deal of mining was carried out. There are no large slag dumps within the mine area. However, the slag dumps at Bairath on which most of the town is built, are very extensive.

Mineralisation : No surface indications of the ore that was mined, are noticeable in the mines or in the rubble except for minor malachite stains. The highly ferruginous bands in the breccia do not reveal any sulphides. Minor specks of sulphides (chalcopyrite and pyrite) are seen in the brecciated granite. Analyses of the slag from near the workings show 750 p.p.m. of copper and 75 p.p.m. of zinc ; the slag from Bairath shows 100 p.p.m. to 2,000 p.p.m. copper and 100 to 300 p.p.m. zinc.

Controls of mineralisation : The main control of mineralisation is the 30.5 m. wide, nearly vertical fault zone traversing across all the rock formations, including the granite, suggesting a post-granite mineralisation. Minor fault breccia zones, which end at or cross the main zone and also the contact between the granite, quartzite and metadolerite, probably also localise mineralisation.

5. Matasula (Pl. 40)

The area is situated about 400 m. west of the village of Matasula and can be reached through Pratapgrah from Thanaghazi on the National Highway.

Rock formations : The rock formations are schists and quartzite, classified under Alwar series by Heron, along with basic rocks.

The schists include a quartz-sericite schist and a quartz-biotite schist. The quartzite is interbedded with the schists and contains microcline, minor tourmaline and apatite, besides quartz.

Thick debris and blown sand cover a large part of the area and exposures are very few. The quartzite occurs as three bands running northwards along the ridge. It is a massive, medium to coarse grained, well jointed, light coloured rock consisting mainly of quartz with minor felspar. The basic rocks are massive metadolerite and hornblende-schist.

Structure : The general strike of the rocks is N.10° to 15°E.—S.10° to 15°W. with the beds dipping westward. The contact between the quartzite and the quartz-sericite schist appears to be along fault.

Old workings : The old workings consist of some narrow shafts and pits extending over a length of more than three kilometres. These can be grouped into two divisions, one being found only in the southern part of the area and the other in the northern part. The workings in the southern part are located on the eastern slope of a north-south trending ridge while those in the northern part occur in the valley which is mostly covered by sand.

Mineralisation : There are no indications of sulphides in the mine debris or in the old workings. The extent of the workings laterally and in depth, the mine debris and the slag are similar to those noted in the Nagel (Pratapgarh) area.

Controls of mineralisation : Despite the extensive sand cover, it is possible to infer that the two faults are the main controls of mineralisation as all the old workings are located along these. The mine debris which consists mainly of schists and breccia, also suggests a lithological control.

6. Bhagoni (Pl. 41)

The Bhagoni area is situated in a rather inaccessible part of the Seriska Game Sanctury, and is approached from Seriska on the National Highway.

Rock formations : Thick vegetation, old slag and mine debris conceal most of the area near the workings ; the only rock exposure seen is a quartzite, at the higher flanks of the steep ridges. Chips of sericite-quartz-schist are seen in the mine debris.

The quartzite is a massive, light coloured and well jointed rock filled along joints with ferruginous matter. The schist is chloritic and contains pockets of limonite which probably represent leached sulphides. Vein quartz and sulphide minerals are seen at some places in the debris.

Structure : Reconnaissance mapping carried out around the mine area suggests major anticlinal folds, plunging to the north and some large north-south trending faults, located both to the east and west of the mine area. Detailed mapping is difficult because of thick vegetation.

Old mine workings : The old workings consist of small-diameter and closely spaced shafts, all being more than nine metres (about 30 ft.) in depth. The shafts are water-logged and inaccessible. There are large heaps of slag and mine debris, the latter including chips of chlorite-schist and vein quartz.

Mineralisation : Surface evidences of copper mineralisation are practically nil. The vein quartz in the mine debris shows pyrite and chalcopyrite. Small specks of pyrite and chalcopyrite are also seen in the quartzite at the eastern end of the line of shafts. Analysis of the slag shows about 70 p.p.m. of copper and about 100 p.p.m. of cobalt.

Controls of mineralisation : Because of extensive cover, it is difficult to make out the controls of mineralisation but the location of the workings in the chloritic schist, which also forms the bulk of the mine debris, indicates that the schist is the host rock. The surface trends of the lines of workings suggest that the N.80°E.—S.80°W. zone would be dipping steeply to the south and that the N.40°E.—S.40°W. zone would be vertical. The directions coincide with the major joint directions of the quartzite, east of the area. It is presumed that the mineralisation is localised along joints in the chloritic schist.

7. Nalladeshwar (Pl. 42)

The mine area is located in an east-west ridge, eight kilometres east of Seriska and adjacent to the National Highway at the 26th km. stone from Alwar.

Rock formations : The rocks of the area are the brecciated quartzite and a blackish banded marble, described as hornstone breccia and Kushalgarh limestone respectively by Heron.

The quartzite is generally massive, well jointed and is brecciated at places. The joint planes are generally filled in by limonitic matter. The quartzite occupies the crest and southern flank of the ridge, whereas the marble, with closely alternating bands of carbonates and quartz, is exposed on the northern flank of the ridge.

Structure : Within the mine area, no major folds or faults have been traced. Outside the mine area and at the western end of the ridge, the marble wraps round the quartzite and shows minor folds which indicate an eastward plunge of the major fold system. On the basis of this evidence it can be assumed that the quartzite (or hornstone breccia ?) is the core of a syncline plunging eastward. More detailed mapping, however, is necessary for deciphering the precise structure.

Old workings : The old workings of the mine can be grouped under (i) open pits with occasional deep shafts along the crest of the ridge, (ii) a parallel line of shafts along the southern flank and (iii) four groups of deep shafts running roughly north-south. The open pits, at the crest, are located in highly brecciated quartzite. Many are up to nine metres in depth and the walls of the workings are in the brecciated quartzite. Shafts located adjacent to such big workings are also about nine metres deep. There is very little mine rubble in the vicinity of these workings. The other two groups of workings consist of small diameter, closely spaced and well lined shafts, upto about 24 m. (80 ft.) in depth. The shafts are filled with rubble at the bottom. The mine rubble from these workings is considerable and consists of brecciated quartzite and schist with major stains of malachite.

Mineralisation : There are no indications of copper mineralisation, except occasional stains of malachite. The slag, which is found in the eastern part of the mine, however, analyses about 500 p.p.m. of copper.

8. Agar (Pl. 43)

The Agar area is situated on a low hill, 800 m. south-east of the village of Agar and is reached from Thanaghazi on the National Highway.

Rock formations ; The rocks of the area include quartzite, friable quartzite and quartz-sericite schist, which have been classified under Alwar series by Heron, along with metadolerite.

The quartzite forms the crest and the northern flank of the ridge. It is white to pink in colour, massive, well jointed and is fre-

quently brecciated, with limonitic fillings. Cross-bedding is commonly seen in the quartzite. The friable quartzite occurs as bands within the schist and consists of quartz, sericite and white clay. The friable quartzite and the schist are filled in along joints by limonitic matter, which stands up prominently. The metadolerite is massive, well jointed and forms the western flank of the hill.

Structure : The trend of the quartzite at the surface and the plunging minor folds seen in a stope indicate the structure to be a syncline plunging about 45° - 50° to the north-east.

Three major faults, all trending north-south, have been traced. The western fault is noticed at the bottom of a large shaft at the northern end where it dips westwards at 45°. The middle fault is seen in one of the pits on the saddle. The eastern fault can also be seen on the saddle, dipping at 65° towards west.

Old workings : The old workings consist of closely spaced and small diameter lined shafts which are from 6 to 30 m. in depth. The majority of the shafts are near the nose of the syncline. Most of the shafts are filled up at the bottom. A shaft at the eastern end of the line of workings opens into two small stopes at 2.4 m. (8 ft.) and 7.5 m. (25 ft.) from the surface. The stopes are about nine metres (30 ft.) in length, 2 to 2.5 m. (6 to 8 ft.) in width and are inclined about 65° to the north-east. The large shaft at the northern end is located mostly in quartzite and touches the schist only at the bottom. The mine rubble consists of friable quartzite and schist. There is a small amount of slag near the village.

Mineralisation : The location of the old workings in the friable quartzite and ferruginous schist and in the fault zones, suggests both lithological and structural controls. The evidences regarding the nature of the ore, however, are inconclusive. The surface indications of copper-ore are meagre, though the soil (dumps) and the slag contain up to 4,000 p.p.m. of copper. In the only accessible stope, the rock is a friable quartzite, with innumerable joint fillings of ferruginous matter, which stand out prominently.

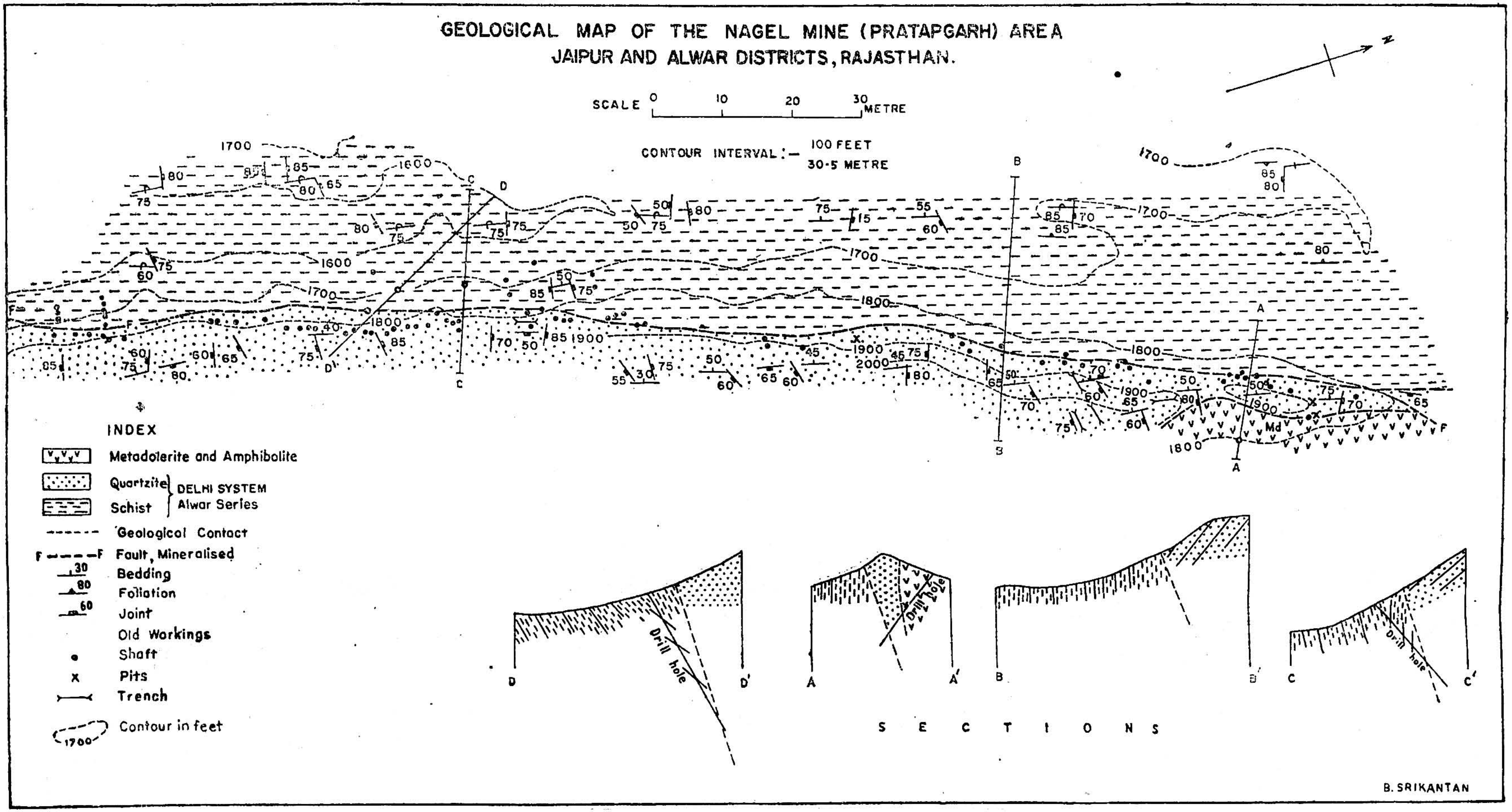
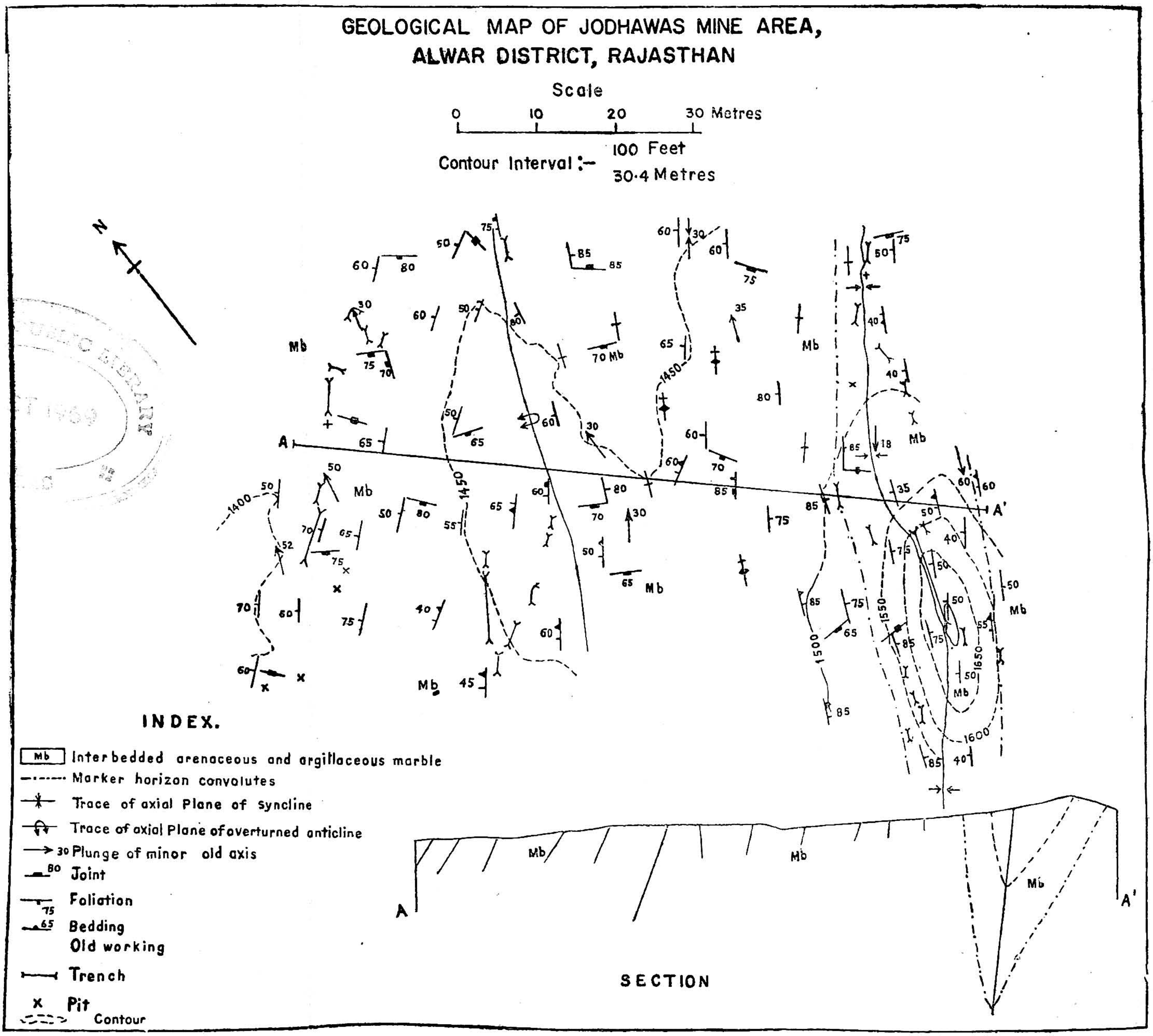

GEOLOGICAL MAP OF THE NAGEL MINE (PRATAPGARH) AREA
JAIPUR AND ALWAR DISTRICTS, RAJASTHAN.
SCALE 0 10 20 30 METRE
CONTOUR INTERVAL :— 100 FEET
30·5 METRE
INDEX
Metadolerite and Amphibolite
Quartzite
Schist
DELHI SYSTEM
Alwar Series
Geological Contact
Fault, Mineralised
Bedding
Foliation
Joint
Old Workings
Shaft
Pits
Trench
Contour in feet
Drill hole
SECTIONS
B. SRIKANTAN

PLATE 37



B. SRIKANTAN.

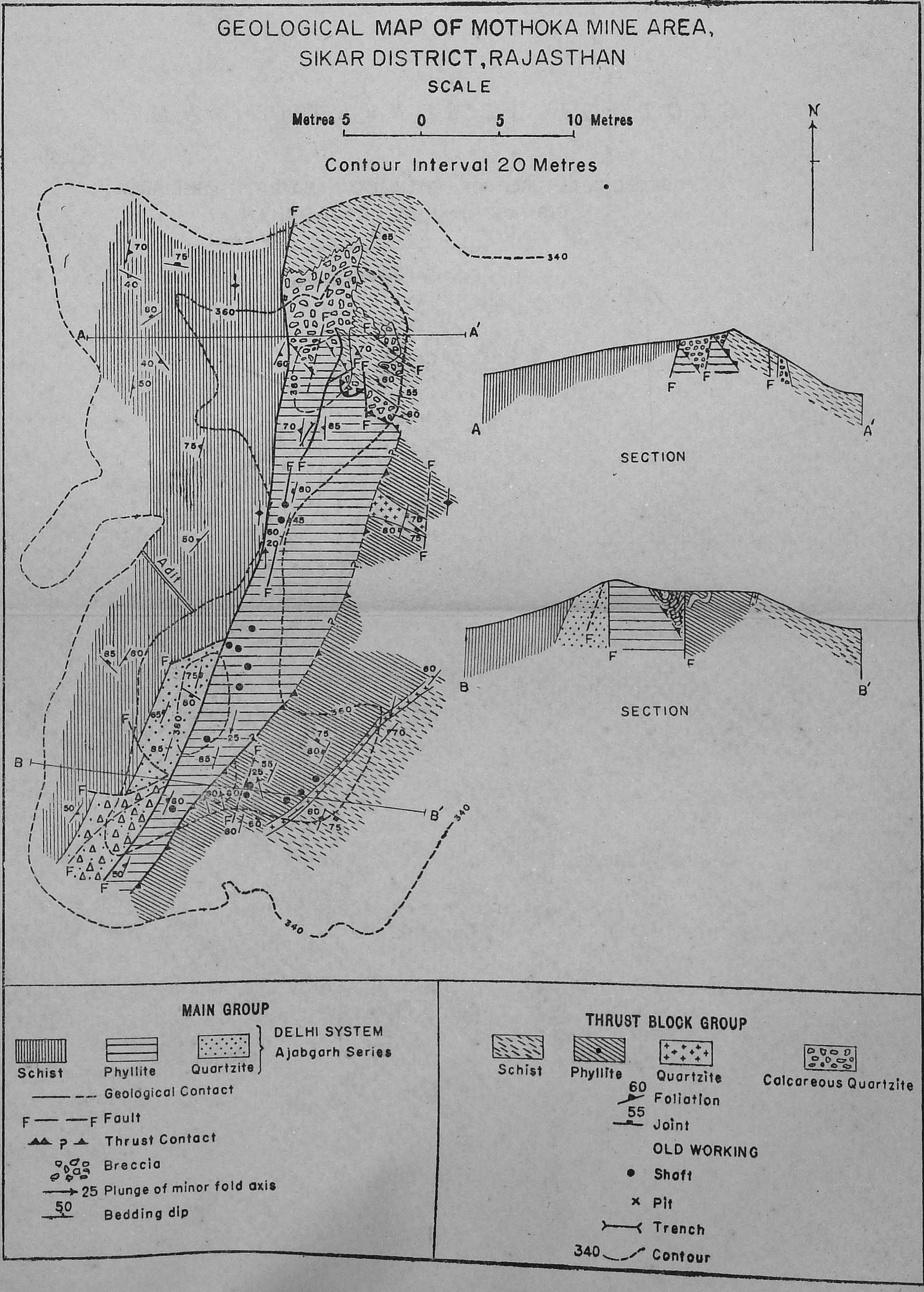

GEOLOGICAL MAP OF MOTHOKA MINE AREA,
SIKAR DISTRICT, RAJASTHAN
SCALE
Metres 5 0 5 10 Metres
Contour Interval 20 Metres
N
A
A'
B
B'
Adit
340
360
380
SECTION
SECTION
MAIN GROUP
Schist
Phyllite
Quartzite
DELHI SYSTEM
Ajabgarh Series
Geological Contact
Fault
Thrust Contact
Breccia
25 Plunge of minor fold axis
50 Bedding dip
THRUST BLOCK GROUP
Schist
Phyllite
Quartzite
Calcareous Quartzite
60 Foliation
55 Joint
OLD WORKING
Shaft
Pit
Trench
340 Contour

PLATE 39

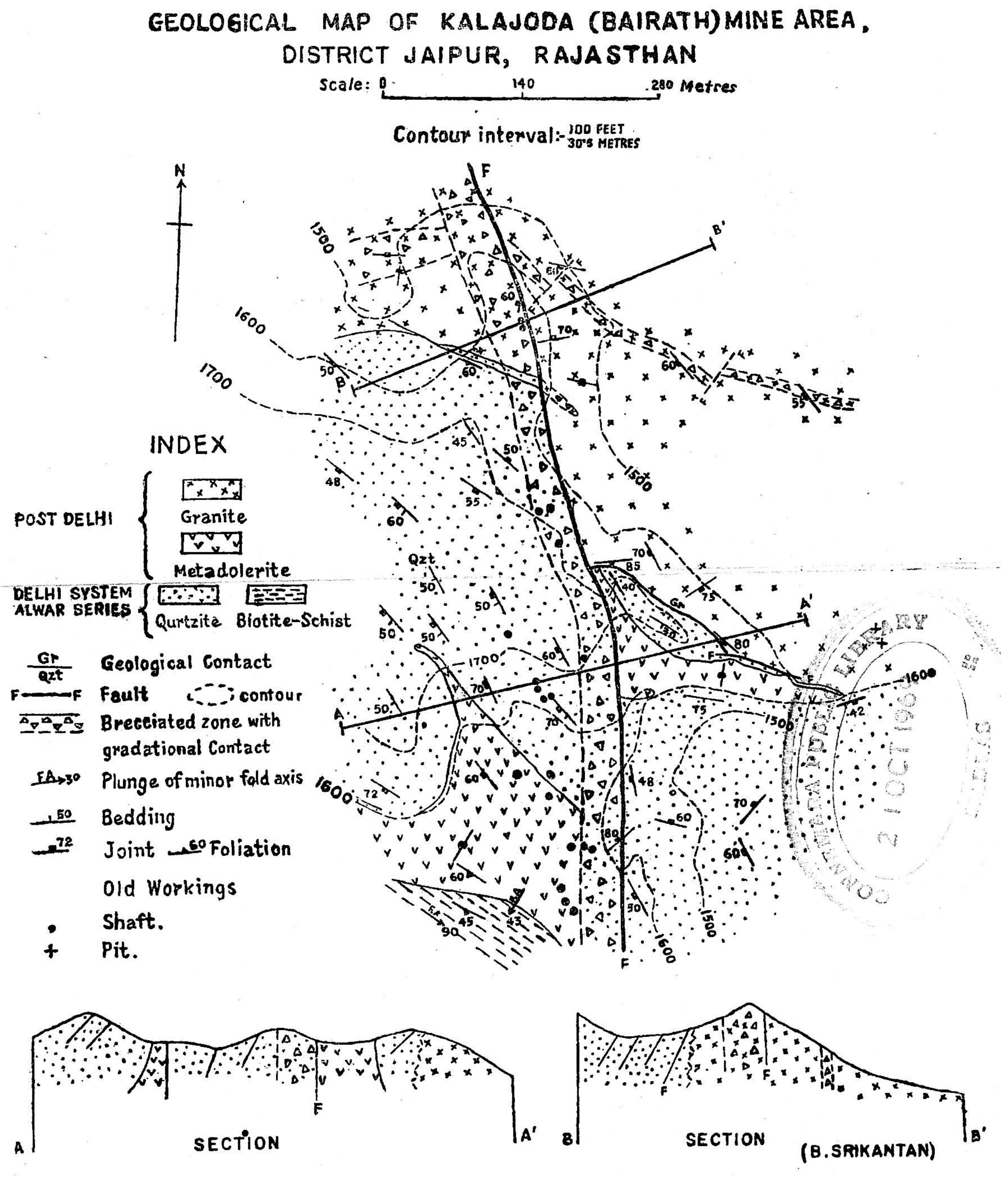


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PLATE 40

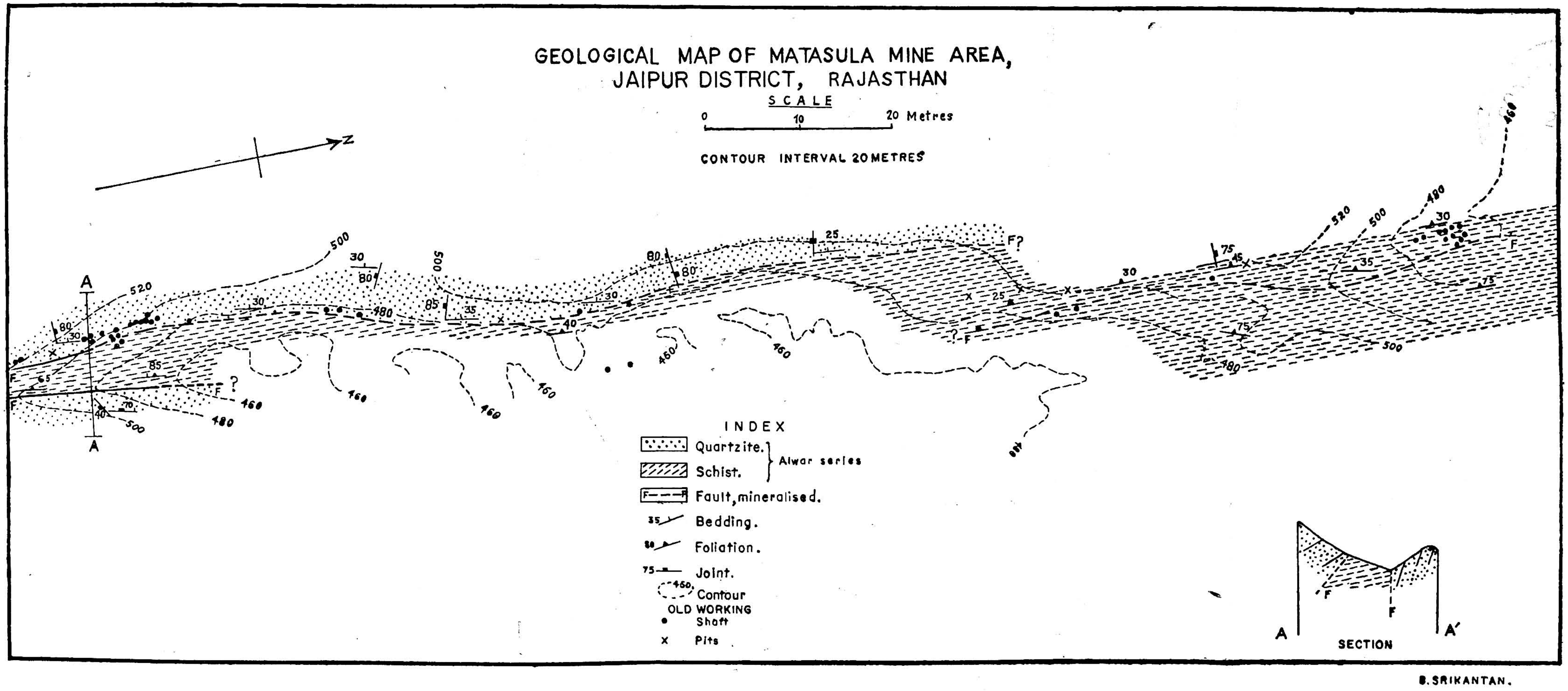
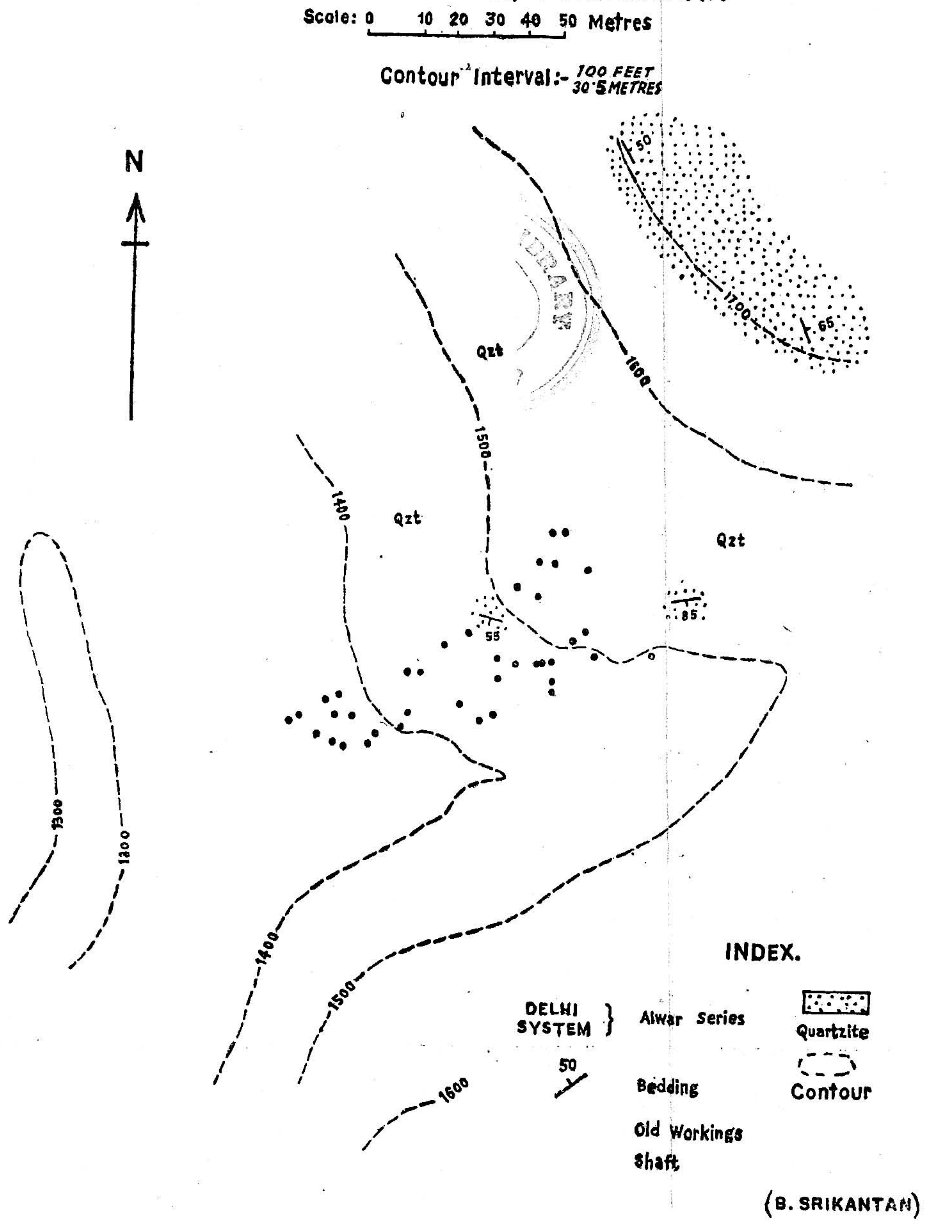

GEOLOGICAL MAP OF MATASULA MINE AREA,
JAIPUR DISTRICT, RAJASTHAN
SCALE
0 10 20 Metres
CONTOUR INTERVAL 20 METRES
N
INDEX
Quartzite.
Schist.
Alwar series
Fault, mineralised.
Bedding.
Foliation.
Joint.
Contour
OLD WORKING
Shaft
Pits
SECTION
A
A'
F
B. SRIKANTAN.

PLATE 41

GEOLOGICAL MAP OF BHAGONI MINE AREA, DISTRICT ALWAR, RAJASTHAN



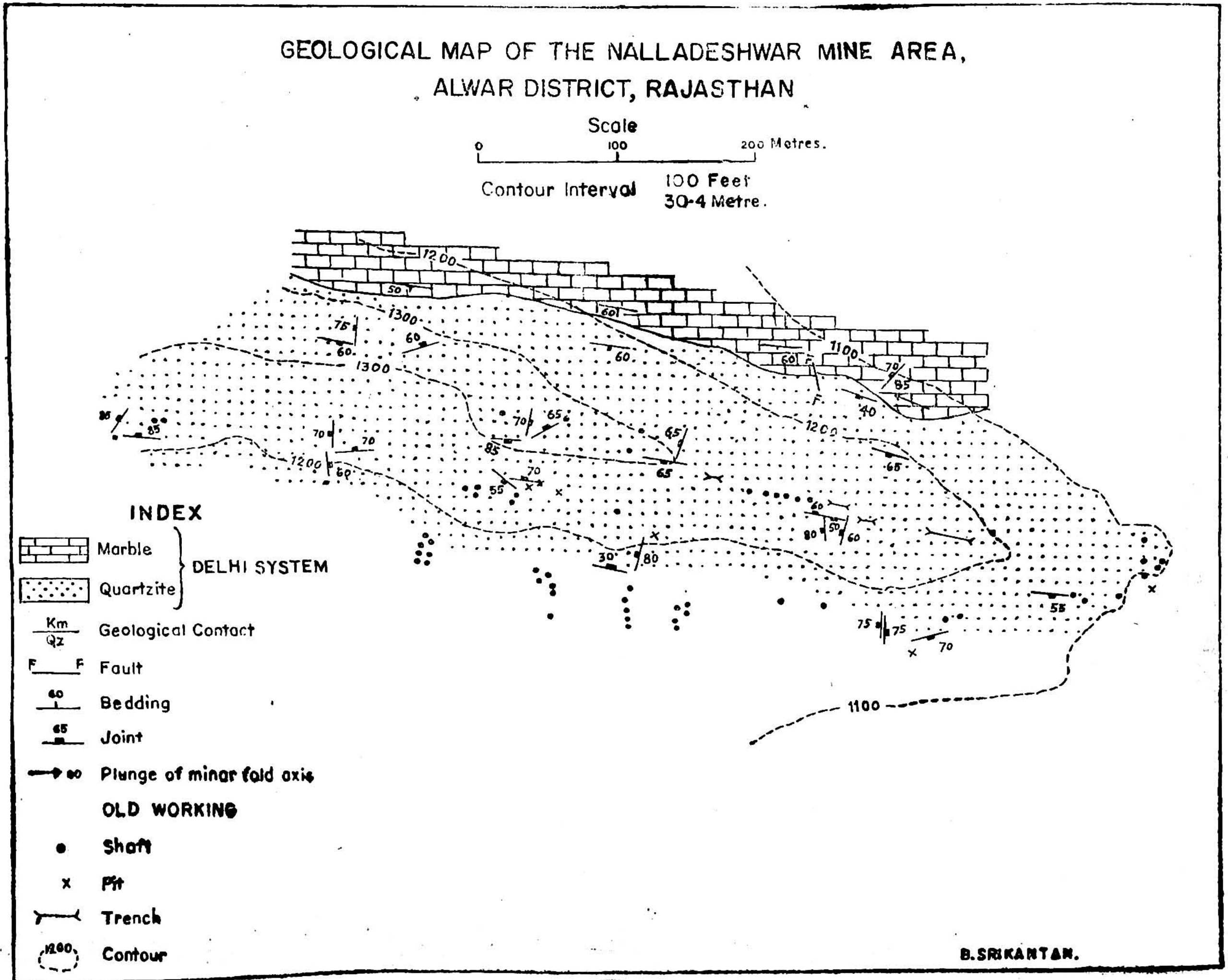
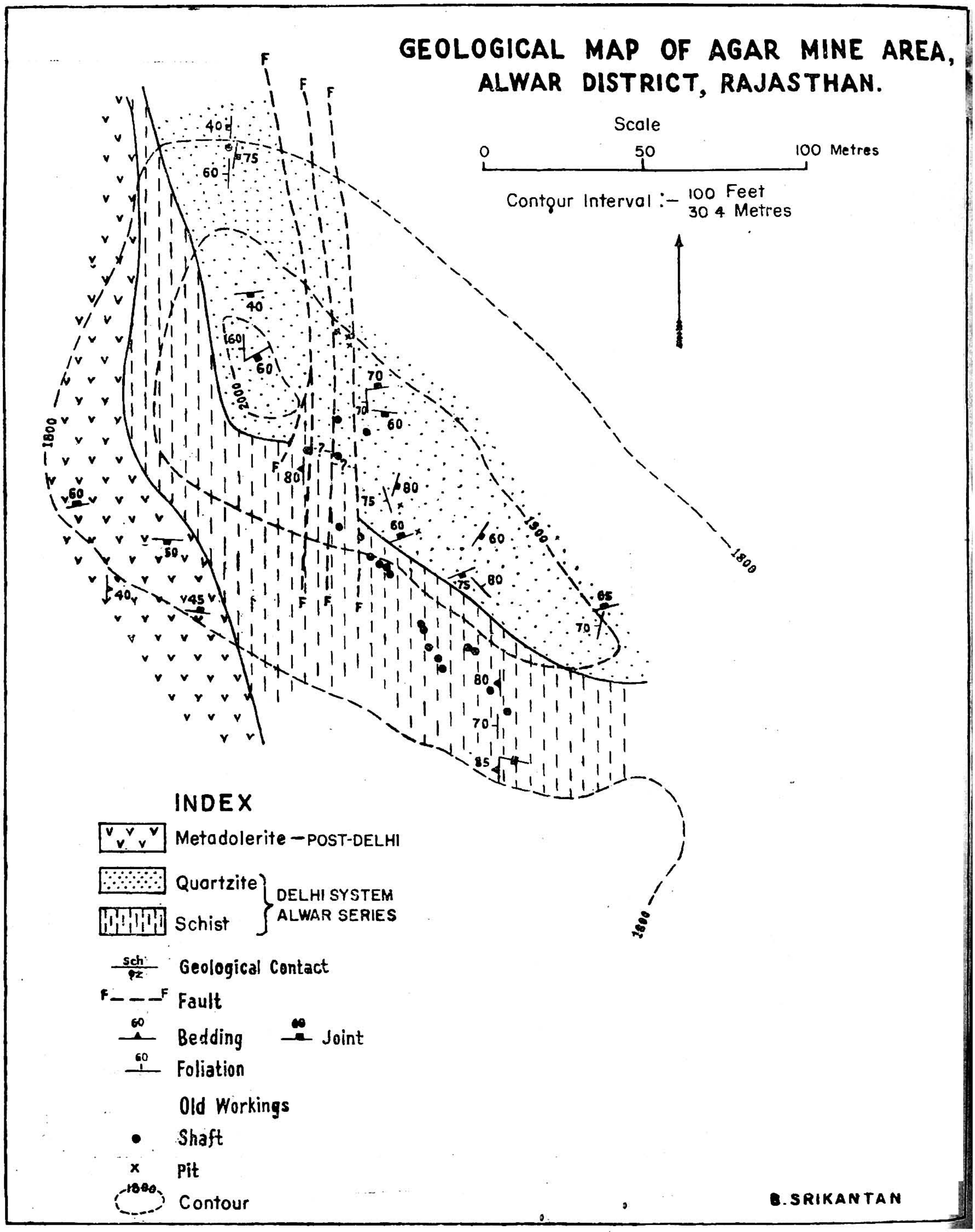

GEOLOGICAL MAP OF THE NALLADESHWAR MINE AREA,
ALWAR DISTRICT, RAJASTHAN
Scale
0
100
200 Metres.
Contour Interval
100 Feet
30·4 Metre.
1200
1300
1100
INDEX
Marble
Quartzite
DELHI SYSTEM
Km
Qz
Geological Contact
F
Fault
Bedding
Joint
Plunge of minor fold axis
OLD WORKING
Shaft
Pit
Trench
Contour
B.SRIKANTAN.

PLATE 43



GEOLOGICAL MAP OF AGAR MINE AREA, ALWAR DISTRICT, RAJASTHAN.
Scale
0
50
100 Metres
Contour Interval :- 100 Feet
30 4 Metres
INDEX
Metadolerite —POST-DELHI
Quartzite
Schist
DELHI SYSTEM
ALWAR SERIES
Geological Contact
Fault
Bedding
Joint
Foliation
Old Workings
Shaft
Pit
Contour
B. SRIKANTAN

CONCLUSIONS

Detailed geological mapping has shown the probable structural and lithological controls of ore mineralisation in these areas. In the Nagel (Pratapgarh) area recent drilling has confirmed the existence of a mineralised fault zone trending north-south. The main problems of drilling in this area are unusually deep old workings and zone of leaching and also the need to carry out drilling from the foot wall side of the fault zone. Deeper drilling, which has been started will provide information regarding the primary zone. In the Jodhawas mine area, the main control of mineralisation may be stratigraphic or structural. In the Mothoka, Kalajoda, Bhagoni and Matasula mine areas, the main controls of mineralisation are faults.

While exploration could be taken up in these areas merely on the basis of extensive old workings and slag heaps, only the interpretation of the probable controls of mineralisation based on detailed geological work could provide scientific grounds for such a programme of work. The exploration of the Dariba mine area is based on such detailed geological mapping carried out by the Geological Survey of India. Despite the absence of surface indications of ore in most of these areas, there are sufficient geological evidences for planning exploratory programme in the areas investigated. Initial exploration should, therefore, be carried out to confirm the controls and to establish the nature and extent of mineralisation.

COPPER MINERALISATION NEAR THE TRI-JUNCTION OF BANKURA, MIDNAPUR AND PURULIA DISTRICTS, WEST BENGAL.

By

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ABSTRACT

A number of copper-ore occurrences are found near the tri-junction of Bankura, Midnapur and Purulia districts, West Bengal. The structural control of the mineralisation has been briefly summarised in the paper. A good number of copper minerals—chalcopyrite, malachite, chalcocite, covellite, cuprite, azurite and native copper together with a host of associated ore minerals—wolframite, scheelite, cassiterite, molybdenite, bismuthinite, magnetite, ilmenite, pyrite, pyrrhotite, sphalerite, hematite and goethite have been found in this area. The hypothesis of mineral zoning modified by distribution of structural breaks satisfactorily explains the distribution of mineral occurrences. Finds of puri-Kushan copper coins dates the ancient copper mining (probably the last mining period before its resumption in Singhbhum during British period) to lie between 200 A.D. to 600 A.D. Geophysical and geochemical prospecting supplemented by drilling will bring out the potentialities of the area.

INTRODUCTION

A number of copper-ore occurrences are located in pelitic schists, phyllites and granite gneisses near the tri-junction of Bankura, Midnapur and Purulia districts, West Bengal. This area (Lat. 22°42′ to 23°00′ and Long. 86°35′ to 86°52′) is the eastern continuation of the Pre-Cambrian terrain of Chhota Nagpur, Singhbhum, Manbhum and Dhalbhum. The earliest reference to the geology of the area dates back to 1823, when Dr. Voysey noted that the rocks around Kuilapal and near Dhadka were mica-schists containing profuse quartz veins. In the first Memoir of the Geological Survey of India (1859), Oldham, Blanford and others gave an account of the geology of 'Bancoorah, Midnapore and Orissa.' The next important reference is Valentine Ball's memoir published in 1881. After the study of the whole terrain

of Chhota Nagpur and adjacent areas, he subdivided the rocks into a metamorphic series and a sub-metamorphic or transition series. He located occurrences of some ore-minerals. The most comprehensive recent report of the eastern part of the area has been given by Dunn, Dutta and Dey (1937) and Dunn and Dey (1942). A numbur of geologists from the Geological Survey of India, Indian Bureau of Mines and Atomic Energy Commission and research students from the Universitses of Calcutta and Jadavpur and T. C. Bagchi (1955) from I. I. T., Kharagpur, have worked on different parts of the area. The present author has carried out his work in this area during the period 1954 to 1961 (Chakravarty 1955, 1958a, 1958b, 1960, 1961).

GEOLOGY

Dunn (1929, 1942) has described the stratigraphy, structure, petrology and economic geology of Singhbhum and Manbhum Pre-Cambrian rocks. The region lies to the north of Dalma syncline and south of Chhota Nagpur granite gneiss including a small portion of it. Two major rocks units, namely metamorphics and granites, constitute the area. The metamorphics include the rocks of igneous and sedimentary origin. The para-schists are mainly pelitic rocks with sub-ordinate psammitic, psammopelitic and calcareous ones. The orthotypes include epidiorites, amphibolites and ultrabasic rocks.

The granites occupy mainly the northern, south-eastern and south-western parts of the area. Following the concept of zonal variation of metamorphism, four provisional mineral isograds (biotite, garnet, staurolite-kyanite and sillimanite) can be laid down. Due to the presence of a good number of index minerals like kyanite, staurolite, sillimanites, garnet and andalusite in close association in different parts, the concept of simple progressive metamorphism appears inadequate to explain the complexities of metamorphism and the author has advocated the hypothesis of polymetamorphism. (Chakravarty, 1961)

While the origin of the granite gneisses in the area is yet to be solved, the Kuilapal granite gneiss fairly resembles in some details the type of mantled dome-gneiss, advocated by Eskola (1948).

STRUCTURAL CONTROL OF MINERALISATION

The area lies between two structural breaks in Singhbhum geology—the boundary fault running near the southern margin of Chhota Nagpur granite gneiss and the Dalma overthrust. Besides, there are hidden shear zones and thrusts, greatly masked due to metamorphism, flow of mica-schists and emplacements of pegmatites and quartz veins. The structural patterns of these rocks have been investigated by statistical analyses of preferred orientation of structural elements such as foliation, lineation, fold axes and joints (Chakravarty, 1960, 1961).

A close study of the air-photographs of the area has revealed a large scale structure of the area. The most persistent vegetation covers garnetiferous mica-schist country often containing crystals of staurolite, kyanite, sillimanite and even andalusite. These medium to high grade pelites serve as the key beds in the revelation of large scale structure. From the disposition of bedding, study of drag folds and cleavage-bedding intersections (rarely distinguishable in quartzose rocks), the structure is shown to be two large anticlines plunging at low angles towards west separated by synclinal areas of smaller dimensions and higher plunge. In mica-schists, all structures including general layering, disposition of general bedding, limbs of folds and axial plane schistosity are all effectively coincident indicating great recumbency of major structure (King, 1956, p. 95). The degree of deformation shows great variations, so that layers preserving original sedimentary structures occur side by side with others in which original structures have been obliterated by shearing. The plunging anticlines simulate digitation anticlines of a large recumbent fold. It is suggested that recumbent folds are the earliest structures and were formed by gliding of sheets of schists and quartzose calc-granulites on a gently dipping surface under the influence of gravity (Weiss and Mc Intyre, 1957). The folds with steeply dipping axial planes have been superimposed on the recumbent fold by sub-horizontal squeezing without large scale translation. The axial plane schistosity shows general dip towards north indicating that the foliation-folds are overfolded towards south. The whole structure is at present the part of a cross folded double plunging fold system with cenvexity of arching towards south. The cross folding which curves the previous axial plane schistosity might have been developed during subsequent pulses of the same orogeny. Three

sets of pucker lineations showing age difference also bear evidence in favour of the polyphase movements. Avoiding details, it may be summarised that the intensity of deformation as also arching due to cross folding increases towards the south, where the folds are closely compressed, assume isoclinal nature and fold closures cannot be distinguished.

The granite gneisses have been reconstituted or emplaced syntectonically with last phase of cross folding movement. The late tectonic pegmatite granites of Chhendapathar and Chapri have been emplaced along a hidden overthrust zone at the culmination of this deformation and themselves bear no imprint of directive or penetrative structures.

The complex fold movements in their different phases have given rise to numerous structural breaks in the country rocks. Both the types of structural breaks—shear breaks and brecciation breaks, with all gradations in between bear evidences of mineralisation. Minor structural controls like intersection of shear joints, sheeted and crushed portions of veins, have been operative in localisation of ores within larger ones.

OCCURRENCE OF COPPER MINERALS

The location of majority of the exposures in the northern part of the area are connected with the great boundary fault running near the southern margin of the Chhota Nagpur granite gneiss. The localities are Mukutmanipur (22°58′ : 86°47′), Nilgiri (22°57′ : 86°43′) Narayanpur (22°48′ : 86°44′) and Sarengarh (22°57′ : 86°44′). The copper occurrences are marked by malachite stains on the country rocks or by a material resembling gossan. In all these places evidences of ancient mining are present. To the east near Tamakhun, south-east of Turapahar (22°49′ : 86°51′) copper mineralisation is found in cherty bands, running parallel to regional foliation of schists. Arsenopyrite, haematite and goethite are present as associated minerals. A rock from a fault zone near Jhilimili (22°49′ : 86°39′) with quartz and iron oxides, gave blue flame of copper. Uuder ore-microscope, the polished specimen showed speaks of chalcopyrite. These fault zone rocks were once used for preparation of indigenous iron. But the practice had to be given up due to high content of

copper. The old galena pits near Nanna (22°47′ : 86°36′) carry copper minerals (chalcopyrite and malachite) and larger crystals of siderite. But the most important copper-ores have been encountered in areas of tungsten mineralisation, especially at Thanpahar (22°45′ : 86°46′) and Purnapani (22°45′ : 86°47′). Besides wolfram, which in most cases approaches ferberite in composition with occasional small percentage of hubnerite, one can study scheelite, cassiterite, molybdenite, bismuthinite, magnetite, ilmenite, chalcopyrite, pyrite, arsenopyrite, pyrrhotite and sphalerite as primary ore minerals, and quartz, tourmaline, muscovite, siderite and sericite as the gangue minerals and a good number of supergene minerals—tungstite, chalcocite, covellite, cuprite, azurite, native copper, malachite, hematite and goethite. Mineragraphic description of these minerals showing interesting textural relations have been published (Chakravarty, 1958).

Hypothesis of mineral zoning

Occurrence of tungsten-copper, and lead-zinc-silver minerals indicate a space zoning around the granite outcrops of the area. High temperature tungsten and copper minerals occur more near the granite and lead-zinc-silver minerals further out (Chakravarty 1955, 1958). Time of formation of minerals in individual occurrence also corroborate the sequence. Complex structural set up of the area has controlled and modified this zonal arrangement by providing favourable channels for these ore-bearing fluids. But the granites still appear to be the loci of metasomatic introduction and mineralisation.

ANCIENT COPPER MINING

As elsewhere in Singhbhum, ancient miners have removed mainly oxides and carbonates of copper. Long tunnels have been discovered at Thanpahar and Purnapani occurrences. Purikushan copper coins were found from Rantara (22°44′ : 86°40′) by the author in July 1954 and a few pieces were presented to Ashutosh Museum, University of Calcutta. Subsequently similar coins of larger diameter have been discovered from Chakadoba (22°46′ : 86°39′). Dunn and Dey (1937) reported the find of such a coin from near Rakha Mines by which they dated the last working period of Bihar copper belt, before it was resumed in the present century to lie between 200 and 600 A.D.

At the downfall of the Kushan powers in India, the people of Eastern India, having plenty of resources of copper, prepared them indigenously. The pieces collected may represent these imitation coins belonging to third to sixth century A.D. These finds add to the evidences of ancient metal mining activities in eastern India.

ACKNOWLEDGEMENTS

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SOME IMPORTANT GUIDES AND METHODS IN THE SEARCH FOR COPPER DEPOSITS

By

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ABSTRACT

Different types of economic deposits for copper are expressed by their characteristic, mineralogical, petrographical, structural, geochemical and geomorphological features which form important guides for searching copper deposits. Six main classes of such economic deposits along with their various guides, which help in searching copper, are stated. The possibility of applying such guides for prospecting copper deposits in various places of India, is mentioned.

Cuprometric survey, a cheap, simple, and quick method, extensively used in U.S.S.R. for copper prospecting, is described, During this survey, the original copper content present in the rock of ore body prior to its removal as a result of leaching is found out. This evaluation can be done by studying different limonitez resulting from the oxidation of sulphide ores. A fairly good relation exists between the character of limonite and the copper content in the primary ore.

INTRODUCTION

The chances of success in discovering hitherto unknown copper deposits depend on the careful choice of a prospecting and searching method or methods suitable for the area to be examined. An area of former copper production, where the presence of mineralisation has already been established, affords the best prospects for finding additional reserves in either the lateral or the vertical extension of the known zones of mineralisation. In areas devoid of old workings, search should be made with the help of certain diagnostic clues indicative of the different types of economic deposits of copper. Since, in recent years, copper has been used increasingly in various industries, even deposits containing as low as 0.5 per cent copper, can be worked economically provided the reserves are large enough and mechanised mining methods are employed.

Search for Copper Deposits

One of the important prerequisites, in searching for copper, or for any mineral, is to have a detailed geological map of the area concerned. On geological maps of scale 1 : 63, 360 or 1 : 31, 680 can be demarcated copper bearing areas and indicating therein all the clues of diagnostic value like, appearance of copper mineralisation, gossan cappings, hydrothermally altered zones etc., and such maps serve as base sheets for the prospect. After delineating favourable areas, more detailed maps of such areas, say on 1 : 1,000 or 1 : 500 may be prepared.

GUIDES FOR SEARCHING COPPER DEPOSITS

Of the various types of economic deposits of copper each has its own characteristics which should be carefully looked for while examining.

1. *Copper sulphide disseminations and veinlets of hydro-thermal origin occurring in sandstones, calcareous shales, slates and dolomitic limestones.*— The metal content in such deposits usually varies from three to five per cent. This group of deposits accounts for 50 per cent. of the copper reserve of the world and yields currently an average of 20 per cent of the world's total production. These deposits frequently contain cobalt (Kreiter, 1960) as an accessory. The possibility of finding copper-ore in such formations increases considerably if the rocks happen to be of shallow water origin, either having marine marginal sags or constituting deposits in troughs within a continental plateau. In such regions, the tectonic history should be carefully studied.

The following guides are helpful in locating such types of deposits :—

(a) Shallow water, variegated formations composed of sandstones and shales, with intercalations of limestones and conglomerates ; ripple marks, mud cracks, etc. are common features in them.

(b) Greenish and brownish grey colour of the variegated formations serve as an indirect sign of copper mineralisation.

(c) Appearance of sulphide mineralisation in the rocks.

(d) Development of a zone of oxidation and appearance of malachite and azurite.

Some of the copper deposits of Rajasthan belong to this group and should, therefore, be investigated on the lines indicated above. The same guides will be helpful in searching for copper in the Narsinghpur district of Madhya Pradesh ; the Salt Range in the Shahpur district of Punjab ; the Chitaldrug district of Mysore ; and the Darjeeling district of West Bengal (Dewan, 1959).

2. *Disseminations and veinlet-type of mineralisation of hydrothermal origin found mainly in intrusive porphyries—porphyry copper deposits.*—The metal content in such deposits usually varies from 0.8 to 2.2 per cent. This group of deposits accounts for 40 per cent of the copper reserves of the world and yields 60 per cent of the world's total output. The ore from such deposits almost always contains molybdenum. (Kreiter, 1960)

This type of mineralisation is confined to the regions of acidic effusives and intrusives emplaced at shallow depths, and is invariably associated with granodiorite-porphyrites, monzonite-porphyrites, alkaline granite-porphyrites, etc. The concentration of copper mineralisation is in the fractured zones of such rocks. The following are certain favourable guides in locating deposits of this type:—

(a) Development of secondary quartzites which have positive geomorphological relief.

(b) Appearance of zones of intensive rock alteration like sericitisation, alunitisation, kaolinisation and pyritisation.

(c) Development of corundum, diaspore, pyrophyllite, margarite, and alustite, etc.

(d) Decomposition of rocks and formation of malachite, azurite and chrysocolla encrustations. In some cases, particularly when molybdenum is associated, the yellow coloured ferro-molybdenite and the greenish grey powellite appear in the oxidised zone. Sometimes gypsum also is met with.

(e) In the areas of secondary quartzites, some small geomorphological depressions are formed, particularly over the host rocks of cuprous mineralisation.

Detailed search with the aid of the above clues can be carried out in the case of the reported occurrences of copper in Jammu and

Kashmir, around Sleemanabad in Madhya Pradesh and in the Kangra district, Punjab (Dewan, 1959).

3. *Hydrothermal cupriferous pyrite deposits associated with basic effusive rocks metamorphosed into sericitic and chloritic schists and alternating with acidic porphyries.*— The metal content in such deposits usually varies from 1.5 to five per cent. This group of deposits accounts for seven per cent of the copper reserves of the world and yields currently 12.0 per cent of the world's total output. These deposits are usually lenticular in shape and also contain other useful metals in addition to copper.

Search for this type of deposits should be carried out in the regions of spilite-keratophyre rocks, differentiating their variants by petrographic methods. The following are some of the more favourable indications and should be marked on the geological map :–

(a) Outcrops of barytes veins and barytised rocks.

(b) Appearance of limonite cappings (gossan) over sulphide mineralisation. Such cappings over the pyritic copper deposits are often developed intensively, and are traceable over long distances continuously. They are occasionally worked for extracting iron or for obtaining residual gold from them.

(c) Zones of opalisation, silicification and whitening of rocks.

Such deposits may be expected in Chitaldrug district, Mysore, where copper also may be found with pyrite, Other promising areas for such search are those where auriferous pyrite-quartz veins occur.

4. *Replacement lodes, veins, and layered skarns with chalcopyrite at granite-limestone contacts.*— The metal content in such deposits usually varies from 2.0 to 8.0 per cent. This group of deposits has about one per cent of the copper reserves of the world and also yields currently almost one per cent of the world's total production.

The search for such deposits should begin with a study of the contact zones of carbonate rocks with hypabyssal intrusives, particularly of the granite—syenite and granodiorite type. The structural contours of the zone of skarn are to be drawn on the geological map. Some very characteristic guides to search for copper-ore in such ore bodies are :–

(a) Development of epidote, amphibole, chlorite, quartz and other minerals of skarn assemblage.

(b) Frequent association of copper and magnetite.

(c) Formation of limonite cappings with appearance of abundant copper carbonates in them.

There are no well known zones of skarn mineralisation in India, but it is worthwhile prospecting on these lines in Pithoragarh, U.P.

5. *Hydrothermal veins, fissure fillings and cmplex sulphide ore-zones in various rock types.* – The metal content in such deposits usually varies from one to ten per cent. This group of deposits contains about two per cent of the copper reserves of the world and yields currently seven per cent of the world's total output.

Structural peculiarities and the controls of mineralisation exercised by them play an important role. Mapping of more complex areas can be successfully carried out on 1:5,000 scale. In prospecting copper deposits of this type, trenches, dug holes and boreholes are usually recommended, specially for detecting 'blind' ore bodies.

In general, Indian copper deposits are widely spread and many are reported to be uneconomic. The guides used in searching for other types of deposits can be successfully applied to these deposits also.

6. *Solid and dissseminated sulphide ores of copper-nickel in the form of lenses and veins associated with basic and ultrabasic rocks.* (Yakzin, 1959) The metal content in such deposits usually varies from 0.8 to 2.0 per cent Cu and 1.3 to 4.6 per cent Ni. That nickel is associated with copper in such deposits makes this group economically important. The important guides to such ore bodies are :–

(a) Gabbro-norite rocks, differentiated from gabbro to pyroxenite anb peridotite in ancient shield areas or at the margin of continental plateau.

(b) Laccoliths, lopoliths or sills differentiated by gravitation or squeezing.

(c) Presence of disseminated sulphides or their schlieren segregated in the intrusive.

(d) Appearance of oxidised zone with limonite cappings, particularly developed with some force on the massive sulphide ore. Amo

ngst oxidised minerals-efflorescence and films of ~~morenosite, garnierite,~~ nepouite, halloysite, annabergite and minerals like melanterite, non-tronite and jarosite are developed.

(e) Depressions over the oxidised and leached exposures of the deposits.

(f) Occurrence of boulders and minute fragments of ore in alluvium.

Such deposits are likely to be met with in India and search on these lines can be carried out in Dandkaranya, Madhya Pradesh, Manipur, N. E. F. A. (Roy, 1960), Jammu and Kashmir and other places where ultrabasic rock are well developed.

Copper is also associated with some of the lead-zinc deposits, and it can be won as a by-product during concentration of these poly-metallic ores.

METHODS OF SEARCHING FOR COPPER DEPOSITS

A very effective and useful method of searching for copper is known as *Cuprometric Survey* (Zenin, 1939), largely used in prospecting over extensive areas, and particularly well suited for the prophyry copper type of deposits. Systematic samples are drawn from all over the oxidised and leached areas, the materials examined under the microscope and compared with the standard collections of the same type. Determination of the copper content in the samples so collected is carried out with the help of the blow pipe.

A standard collection contains 30 samples, which are classified into six groups, each containing five samples as follows :

Group	Copper percentage	Character of the flame
Group— 0	Without ore.	No colouration of flame.
Group— I	With copper content 0.0—0.2 per cent.	Coloured flame, weekly seen, halo about 2 mm. wide.
Group— II	With copper content 0.2—0.5 per cent.	Blue halo up to 5 mm. width.
Group— III	Copper content 0.5—1.0 per cent.	Blue aureole, width up to 10—12 mm., internal portion of the flame is coloured green.
Group— IV	Copper content 1.0—3.0 per cent.	Aureole of flame 15—30 mm. wide, deep green colour, yellow tint.
Group— V	Copper content more than 3.0 per cent determined by microscopic method.	

The samples are drawn from clear, fresh exposures of dug holes ; four from the different corners and one from the centre of the prospecting hole. The network of profile for sampling in areas of good rock exposures, should be 20 × 20 metres and in covered areas 50 × 50 metres.

The results of the survey are plotted on a map of scale 1 : 5,000 and by interpolation lines are drawn through points of different concentrations to determine the maxima of geochemical anomaly. This method can be used in detailed search or even in exploration.

In this method, the copper content originally present in the rock or ore body prior to its removal by leaching, is found out. Such determination can be done by studying the different limonites resulting from the oxidation of sulphide ores. A fairly specific relation exists between the character of the limonite and the copper content in the primary ore from which it has resulted. The products of oxidation and leaching of disseminated copper are classified into six groups (Goodalin and Kovalev, 1951) as follows.

Group—O : Copper content in primary ore is 0.1 per cent. Weakly altered rocks ; limonite is absent, or present in small quantities. Reaction for copper with blow pipe is negative,

Group—I : Copper content in primary ore is 0.1—0.25 per cent. Some igneous rocks fall in this group with abundant colouration caused by different transported limonites (mainly formed by leaching of pyrite). The character and the large content of the limonite indicates the predominance of iron bearing minerals in the primary ore. Reaction for Cu is barely seen.

Group—II : Copper content in primary ore is 0.25—0.50 per cent, characterised by limonitic stains on igneous rocks. Limonite in the form of greyish and blood coloured clots is characteristic. Usually the total volume of such limonite is about 3.5 per cent. There is a course cellular box-work of residual limonite, about 2.0—3.0 per cent. by volume which indicates the presence of sulphides—about 1.5—5.0 per cent pyrite and 1.0—1.5 per cent. chalcopyrite. Reaction for copper is weak.

Group—III : Copper content in primary or is 0.5—0.7 per cent. Igneous rocks are highly altered and easily coloured by limonite. Residual limonite may be as (a) coarse cellular box-work, 2.5—3.5 per cent by volume indicating presence of sulphides—1.0—2.0 per cent pyrite and 1.5—2.5 per cent chalcopyrite, (b) fine cellular box-work 1.5—2.5 per cent by volume, derived from chalcopyrite of the primary ore.

Resinous limonite may be present in this group in the form of fine cellular box-work, but coarse one is very characteristic of this group with distinct reaction for copper.

Group—IV : Copper content in the primary ore is 0.75—1.0 per cent. Highly altered rocks with veinlets of mainly fine cellular box-work of limonite, 2.5—3.5 per cent by volume. In the primary ore the predominant mineral must be chalcopyrite 2.5—3.5 per cent, when the pyrite content does not exceed one per cent. The transported limonite in this group is subordinate. Marked reaction for copper.

Group—V : Copper content in the primary ore is 1.0 to 3.0 per cent. Highly altered igneous rocks with veinlets and concentration of fine cellular box-work of limonite, more than 3.5 per cent by volume. The primary ore before leaching contained mainly chalcopyrite, more than 3.5 per cent by volume, and pyrite was either completely absent, or present in very small quantity. Verp sharp reaction for copper.

When carbonates of copper are well developed, the evaluation of the copper content in rocks during the cuprometric survey can easily be done.

Recently, Warren and Delavault (1959) used simple chemical methods to analyse the readily extractable copper of plutonic rocks and tried to find the dispersion of copper in the vicinity of mineralisation and in non-mineralised areas. The concentration was five to ten times greater in the former case. The technique is very simple and has a great promise in exploration and prospecting for copper.

CONCLUSIONS

In general, the Indian copper deposits consist of disseminations, fracture fillings and fissure vein types (Brown & Dey, 1955) of moderate size and very few belong to the first and second types mentioned above. Many deposits were mined, probably for many years and abandoned. The evidences of such ancient workings have been found in many parts of India (Jhingran, 1959). Such places should be given top priorities for proving additional reserves along either the lateral or vertical extension of the known zones of mineralisation. The methods and guides described in this paper may be of some help in prospecting.

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GEOLOGICAL ENVIRONMENT AND THE SEARCH FOR DEPOSITS OF BASE METALS

BY

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ABSTRACT

The geological environment is a significant factor in the search for zones of copper mineralisation.

Certain specific horizons, are indicated for careful search by geochemical techniques. Data on a new mineral deposit in Gujarat show that the Deccan basalts are likely to reveal base metal deposits of the replacement and contact metamorpic types, at their contacts with older sediments. The amygdular lava flows of the Deccan basalts also merit careful search for possible native copper.

It was once suggested that a "Mineral (Gold) is where you find it". With the development of improved analytical techniques, knowledge on distribution of minor elements in rocks of the crust, and the ideas envolved during prolonged studies in the various mining districts in North America and Europe, we are in a position today to say that a "Mineral is where it should be". The days of exploring ancient workings are practically over, (fortunately we still have some scope for this in India) and one has to concentrate on deciphering potential geological structures favouring ore deposition. After localising such horizons the next logical steps would be to carry out intensive geochemical and geophysical surveys and drilling. The author feels that special attention should be paid to the following geological horizons in India to discover possible mineralisation of copper and base metals.

1. Lava flows of the Archaean which have been reconstituted to schistose rocks (for possible copper occurrences of the Lake Superior type).

2. Density stratified, ultrabasic complexes in the Archaean, as they

sometimes carry sulphide horizons (pyrrhotite, pentlandite, chalcopyrite paragenesis) due to liquid immiscibility. (Similar to Insizwa, Bushveld and Sudbury stratiform complexes).

3. All shear zones in the Archaean adjacent to large bodies of magmatic or metasomatic granite as there are possible horizons of mineralisation induced by mineralising fluids accompanying the granite (replacement deposits).

4. Contact zones of intrusions in the Cuddapah and Vindhyan systems.

5. The amygdaloidal lavas in Deccan basalts for possible occurrence of horizons carrying native copper ; there are references to occurence of native copper in the Deccan basalt in the older literature.

6. The contact zone of the Deccan lavas, and their eruptive equivalents, with sedimentary formations, for possible contact metamorphic or replacement deposits.

The author would suggest that every known minor occurrence of copper and other base metals should be thoroughly investigated to determine their geological environment. This would not only help in development of these deposits, but also offer general clues for future search. Recent literature on mineral explorations in various countries reveals how much has been achieved by application of integrated data on geological structure, and geochemical affinities of elements. The association of niobium with alkalic rocks, titenium with anorthosites, vanadium and chromium with mafic complexes, and rare earths with carbonatites are well known examples of this general concept.

The Deccan basalts covering an area of 500,000 sq. km. represent an enormous volume of basaltic material, even assuming an overall thickness of only 330 m. The total quantity of various metallic elements in this vast amount of basalt would be very large. It is logical to expect concentration of some elements from this basalt under favourable conditions permitting their migration to suitable host rocks. Demonstration of this cencept has resulted in the recent

discovery of large scale fluorite mineralisation at Amba Dongar is Baroda district of Gujarat, induced by variants of Deccan basalt. But there are indications of the presence of lead and certain radioactive rare earth elements in the same general horizon.

It is suggested that a careful analysis of all the available geological literature and old geological maps will enable us to formulate an energetic programme of prospecting for copper and other base metals.

SELENIUM FROM COPPER SMELTING INDUSTRY

By

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ABSTRACT

Selenium is one of the important by-products from the copper smelting industry and can be economically recovered. Investigations have shown that chalcopyrite from Singhbhum contains selenium. Ores from other localities are being studied.

Samples of products from different stages of copper smelting in Singhbhum district were investigated. Copper-ore (concentrate) showed a selenium content of 0.04 per cent, while the copper matte and copper ingot (fire refined) had 0.056 and 0.064 per cent of selenium respectively. The flue dusts and slags from various stages also showed appreciable selenium content. Recovery of selenium from some of the products will considerably improve the economy of the copper smelting industry and at the same time help the national economy by materially reducing the import of selenium.

INTRODUCTION

Selenium is one of the most valuable rare elements. Its chemical and electrical, specially the semi-conductor and photo-electric properties, have led to its use in wide fields covering glass, electrical and chemical industries. So far India has been importing the metal for its entire requirements, the import figure of selenium during the year ended in March 1961, being 7,614. kg. valued at Rs. 4,47,259. The consumption of this metal will considerably increase with rapid industrialisation of the country during the Third and subsequent plan periods. Much foreign exchange may, therefore, be saved if an indigenous source of selenium can be found.

Selenium occurs as a trace constituent in many rocks, minerals and soil. But it has been generally known that it has more pronouced association with sulphur (volcanic) and sulphide ores. Investigations by the Geological Survey of India on the various sulphide minerals, have shown that chalcopyrite from Singhbhum contains selenium. Incidentally, it may be mentioned that volcanic sulphur from barren islands, Andamans, contains appreciable amount of selenium.

The occurrence of selenium in the chalcopyrite from Singhbhum has led to the present investigation in which starting from the copper-ore concentrate, all the products in the different stages of the copper smelting industry were investigated. The samples were received through the courtesy of Messrs. Indian Copper Corporation.

Outline of the procedure for estimation of Selenium

The sample was decomposed with fuming nitric acid and fumed with sulphuric acid. Selenium was separated by distillation with bromine-hydrobromic acid mixture in a specially designed all glass distillation apparatus. Selenium collected in the distillate was precipitated by sulphur dioxide and hydroxylamine hydrochloride. The precipitated selenium was filtered in a gooch and weighed.

Table 1 shows that an appreciable amount of selenium is retained in the copper ingot, ore, matte and blister copper. It is interesting to observe that the selenium contents of the flue dusts are also considerable. The relative amounts of dusts produced in the Roaster and Reverberatory furnaces are 0.01 and 0.05 tonne respectively per tonne, of copper ingot. It will be significant if these flue dusts can be treated so as to recover selenium economically. In the case of slags too it is not insignificant ; specially in refinery slag, the amount is 0.13 per tonne of copper ingot. The selenium contained in slags of various stages is automatically retained in the process as most of the slag is recycled.

Table—1

No.	Sample	Selenium Percentage
1.	Copper-ore (concentrate)	0.040
2.	Copper matte	0.056
3.	Blister copper	0.053
4.	Copper ingot	0.064
5.	Roaster flue dust	0.050
6.	Reverberatory furnace flue dust	0.030
7.	Converter flue dust	0.030
8.	Reverberatory slag	0.013
9.	Refinery slag	0.050

The anticipated production of copper ingot in India during the third plan period is 18,300 tonnes. It may be seen from the above results that about 8,165 kg. of selenium can be recovered from this industry, which will nearly meet the whole requirements of our country.

The investigation is being continued with chalcopyrite from Rajasthan and other places.

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BIOGEOCHEMICAL PROSPECTING FOR COPPER

By

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(With Plates 44-45)

ABSTRACT

The paper deals with the behaviour of copper in soils and plants and the relationship existing between the copper content of soil and plants. An account of the biogeochemical method of prospecting for copper is given, emphasising on the specific sampling techniques for soil and plants. The problems of its application for searching copper-ore deposits in India are discussed.

INTRODUCTION

Biogeochemical prospecting is based on the study of a definite change of metal content of soils, and plants growing over an ore body. There is a direct relationship between the higher metal content of rocks, soils and plants growing over them. The use of plants and upper horizon of soils are the specific peculiarities of this method of prospecting, differing from metallometric survey and other geochemical methods (Maliugua *et al* 1959).

ACCUMULATOR PLANTS

Vinogradov (1954) classified accumulator plants into two groups. The first of these is termed 'biogeochemical province' and includes all those plants which contain a high concentration of certain chemical elements. This type is of great help in prospecting. The second group comprises those plant species which always contain a higher concentration of certain elements in comparison to their neighbouring species. This type has less value in prospecting. The following is the list of indicator plants for copper.

Plants	Place where observed
Alsine verna *Armeria halleri* *Armeria compestris* *Silene otitis* *Miclicheteria nitida* *Scoplophila bigata* *Melampyrum*	On Mansfield cupreous schists, Germany : in Germany and Czechoslovakia on copper deposits.
Viscaria alpina *Melandrium dioicum* *Polysarpaea spirostylis*	On sulphide copper deposits of North Norway, North Australia and in Queensland.
Amorpha conescens	On sulphide ore, Missouri (U.S.A.).
Boutelena rothrockii *Eschscholtzia mexicana* *Quercus turbinella*	On copper rich soil, Arizona (U.S.A.).
Melandrium rubrum *Agrostis alba*	On soil, Czechoslovakia.
Gypsophila patrinii	On copper deposit, Rudnyi Altai, (U.S.S.R.).

Frequently, various modifications in the morphological characters are seen in the plants growing over metal-rich soils. Some good indications are stunted look, slow growth, untimely bearing of flowers, fruits and seeds, partial or complete reduction of certain parts or organs, clustering, withering and premature falling of leaves and chlorosis, etc. (Tkalich, 1959). Sometimes when the metal content in soil increases beyond the plant tolerance, either the plants die soon after they grow or seeds do not form at all, This is particularly true with high copper content of soil.

Plant Physiology And Copper Intake

The absorption of salts by plants depends mainly on the pH value of the soil. The cation absorption increases in acidic

medium (Low pH) whereas anion absorption increases with the increase of pH (Thyssen, 1942). Apart from this, other factors remaining constant, the metal content of plant ash of a particular species depends on the salts present in water, soil or rocks. The relationship between the copper content in soil and plant ash of *Matthiola incana* is given in Plate 44. (after Tkalish). It is apparent from this figure that copper content in plant ash increases with that in soil up to a certain limit. Further increase of copper in soil is not noticed in the plant ash and only when it becomes very high in soil, the copper content in the ash also rises sharply. At this stage, some adverse effects on the plant appear in the form of diseases or else it dies due to copper poisoning.

The quantity of metal absorption is also affected by plant growth. Many plants absorb more metal up to its flowering stage but tremendously reduce the same in subsequent period.

DISTRIBUTION OF COPPER IN SOIL

A study of the distribution of copper in soil is important for prospecting. The soils overlying the copper deposits and the plants growing thereon tend to get exceptionally rich in copper. The content in soil increases usually in tenths of one per cent. Within the limits of copper deposits (Vinogradov, 1950). In different types of soils, copper is concentrated differently at various horizons of soil profiles. This variation is well brought out in the graphs given in Plate 45 (after Lahin and others, 1952). From the profile it is clear that there is a great influence of biogenic factors in copper distribution. Usually copper content increases in upper horizons of soils following the increase of humus, particularly in alkaline soils rich in organic matter and fine fraction of soil. Copper is removed from acidic and neutral soils during leaching process by water (Podzol and Solonetz) resulting in the depletion of copper from the alluvial horizon of these soils (Ginzberg, 1960).

Indications of Biogeochemical Anomalies

From the above considerations, it is clear that a very complex relationship exists between the metal concentration in plant ash and in

soil or bed rock. The biogeochemical anomal caused by such concentrations are indicated by the following :—

(1) *Increase in concentration of copper in soil and plant ash of a particular species :* The plant ash in non-mineralised area has usually 5 x 10^{-3} per cent Cu and in mineralised areas 1 × 10^{-1} per cent Cu, while soil has 2 × 10^{-3} per cent Cu and 1 × 10^{-2} to one per cent Cu respectively (Vinogradov, 1954).

(2) *Increase in concentration of more than one metal in the plant ash, for example, Ni, Co and Cu; Cu and Mo; Pb, Zn and Cu :* In such cases (a) the individual metal content in plant ash and the total metallic concentration is higher than that in the plants of the same species growing on 'barren' rocks. (b) The total concentration of metals in ash of plants growing on a particular deposit is higher than in ash of same plants growing on 'barren' rocks but any one metal in the plant ash in the first case may be less than in the second case (Maliugua, 1954)

(3) *The variation of ratio of different, chemically similar elements contained in the ash of plants growing on the deposits and beyond the deposits i. e. ratio of Zn: Cu, Ni: Cu, Cu: Mo etc. ;* This holds good for metal contents in soil also.

(4) For prospecting purposes, in general, the areas containing less than 0.006 per cent Cu is regarded as sterile, 0.007—0.06 per cent Cu as dispersed mineralisation, 0.07—0.1 per cent Cu as weakly enriched mineralisation and 0.11—0.3 per cent Cu as strongly enriched mineralisation (Ginzberg, 1960).

General Observations on Biogeochemical Prospecting for Copper

While prospecting, it is necessary to be familiar with the geology and geobotany (distribution of different plant species in relation to geological formations) of the region. In addition, tectonics (faults and big fractures), lithology and mineralisation should also be taken into consideration as they also affect the plant distribution and metal content in them. Geohydrological conditions of the region, the thickness and type of soil, its composition, pH and origin should be carefully studied.

Considerable attention should be paid to the distribution of indi-

vidual plant species and specific type of vegetation growing on different bed rocks. In this connection the following observations are important : (a) presence of some specific plants or indicator plants on the ore bodies and associated rocks; (b) change in external appearance and morphological modifications of plants as a result of change in environment (due to mineralised zone) and (c) change in plant associations due to change in lithology.

After such a reconnaissance survey of the area, one should decide about the plant species suitable for taking samples, sampling net work etc.

SAMPLING AND ANALYSIS TECHNIQUE

(1) *Selection and sampling of plants and soil* : Any plant species can be taken for sampling, but different plants accumulate different amounts of the same metal. In order to get comparative results, a single plant species or at the most two or even more plant species which are very closely related to each other should be selected (Rankama, 1941). For example, Warren and Delavault (1955) found that Cu and Zn content in the ash of *Picea glauca* was less than in the plant ash of *Picea maritima.* The plant species selected for sampling must have sufficient distribution within the area. In order to get satisfactory results of chemical analyses of plant ash, biogeochemical samples should be taken from one and the same organ of a selected plant species. Roots are not convenient as they are buried sometimes quite deep in soil and are liable to be contaminated with soil. Usually leaves or entire plants, if they are small (excluding roots), are taken. In case of shrubs and trees, leaves and small branches are preferable. The sample should be taken from trees and plants of approximately the same age.

Any time is suitable for taking samples, though the period immediately after rainfall may be avoided. Summer and autumn are preferred as there is a seasonal variation in the metal content of plants (Tkalich, 1959). The leaves of a plant contain more metal in autumn before they are shed. Due to change in the pH of soil during heavy or prolonged rains, the metal content of the plants appreciably falls.

The plants are taken from within a radius of five metres from a sampling point. The soil samples are collected from the humus horizon of a soil profile on the sampling point. The quantity of plants collected should be enough to give about five grams of ash. About 500 gm. of soil sample should be taken.

(2) *Choice of sampling profiles :* The sampling profile can be either linear, rectangular or a network of squares. The network profile can be from 15 × 15 to 200 × 200 m. or from 50 × 10 to 200 × 40 m. Depending upon the inferred form and dimension of the ore body, Tkalich (1959) recommends the following :—

No.	Supposed form of ore body	Possible dimension of ore body in plan	Search Profile in metres
1.	More or less isometric with simple contours.	Fairly big, probably up to a few hectares.	Square 200 × 200.
2.	Same with complex contours.	—do—	Square 100 × 100.
3.	—do—	Comparatively small.	Square 50 × 50.
4.	Stretched in one direction.	Hundreds of metres along the strike, width of outcrop in plan more than 20 m.	Rectangular 200 × 50.
5.	—do—	Same as above but width of outcrop on plan 10-20 m.	Rectangular 100 × 25.
6.	—do—	Up to 100 m. along strike, width of outcrop less than 10 m. in plan.	Rectangular 100 × 10 or 50 × 10.

To get a good idea of the itensity of biogeochemical anomaly, it is necessary to take samples of soil and plants, not only from mineralised areas, but from non-mineralised areas also.

(3) *Treatment and analysis of samples :* Normally the leaves are dried in sun then burnt. The ash is collected in a crucible and again

heated in muffle furnace at 450°—500°C for an hour to assure complete combustion. It is then ready for chemical analysis. A description of the treatment and analysis of soil and plant ash for copper has been given by various investigators.

INTERPRETATION OF BIOGEOCHEMICAL ANOMALIES

The anomalies can be of two types. One, where the concentration in plant ash increases hundred times the background value, called intense anomaly ; the other, where the concentration shows a little rise, hence called a weak anomaly. Similar anomalies are obtained by study of soil. A strong anomaly is not necessarily a better indication of an ore body than a weak one (White and Allen, 1954). The interpretation of the two types are given below ;—

(A) Intense anomalies arise when (1) an ore body occurs at shallow depths where roots can reach the zone of primary aureole of dispersion ; (2) an ore contains high metal percentage and (3) ore minerals easily alter to water soluble secondary minerals in supergene zones.

Some copper deposits show such intense anomalies. Iron is always concentrated in plants growing over sulphide deposits and since Fe is less mobile in oxidised zone, it can indicate the nearness of other sulphide ore bodies. According to Warren, Delavault and Irish (1952) Fe and Mn anomalies in plants are related to the presence of sulphide ore bodies.

(B) Weak anomalies arise when—(1) an ore body which has low metal content occurs at a shallow depth from the surface ; (2) an ore body which occurs comparatively at greater depth from the surface, may be rich ; (3) an ore is composed of minerals which do not readily alter, and do not form water soluble secondary minerals ; (4) due to climatic conditions chemical and organic weathering is negligible and (5) rocks enclosing an ore body are porous as a result of which ore deposits may form extensive aureole of dispersion having a low concentration of metal.

Such weak anomalies in areas with rich ore deposits were found by Marmo (1953) for Mo, Zn and Cu ; Warren and Delavault (1955) for Cu and Zn ; Harbough (1950) for Pb, Cu and Zn, etc.

Utility of Biogeochemical method of Prospecting for Copper

This method is specially suited for prospecting 'blind' ore bodies which are covered by alluvium, glacial material, etc., having thickness from 5 to 30 m. It gives very good results where podzol soil and marshy land exist. There is a controversy over the depth of ore bodies detectable by this method. Vinogradov (1954) assigns 50 m. as successful depth for locating copper deposits. The depths indicated by other investigators are tabulated below—

Elements	Thickness of rocks over the deposit (in metres)	Determined by analysis of	Author
Ni, Co, Cu, Cr	30	plants and soil	Maliugua (1954)
Cu, Zn	10	plants	Warren and others (1952)
Cu, Zn	10	plants	White (1950)
Cu	5	soil	Sokoloff (1951)
Cu	50	soil and plants	Clarke (1953)

Problems of Practical application in India for Searching Copper deposits

There are many reported occurrences of poorly mineralised copper deposits of various dimensions scattered throughout India. Biogeochemical methods of prospecting may be employed to prospect these. Many deposits may be concealed by alluvium. The main problem in such deposits is to differentiate between the copper anomalies caused by detrital minerals contained in the alluvium, transported from mineralised outcrops and anomalies caused by copper carried upwards in solution from underlying ores and rocks, and precipitated in the alluvium. The knowledge of the distribution of soils in India is necessary. Various copper indicator plants can be established by the study of known deposits which are being mined. The behaviour of copper in soil, rocks and plants with respect to its dispersion can be studied in

mineralised and adjacent non-mineralised areas of different regions. once these facts are established further biogeochemical prospecting for copper will be easier.

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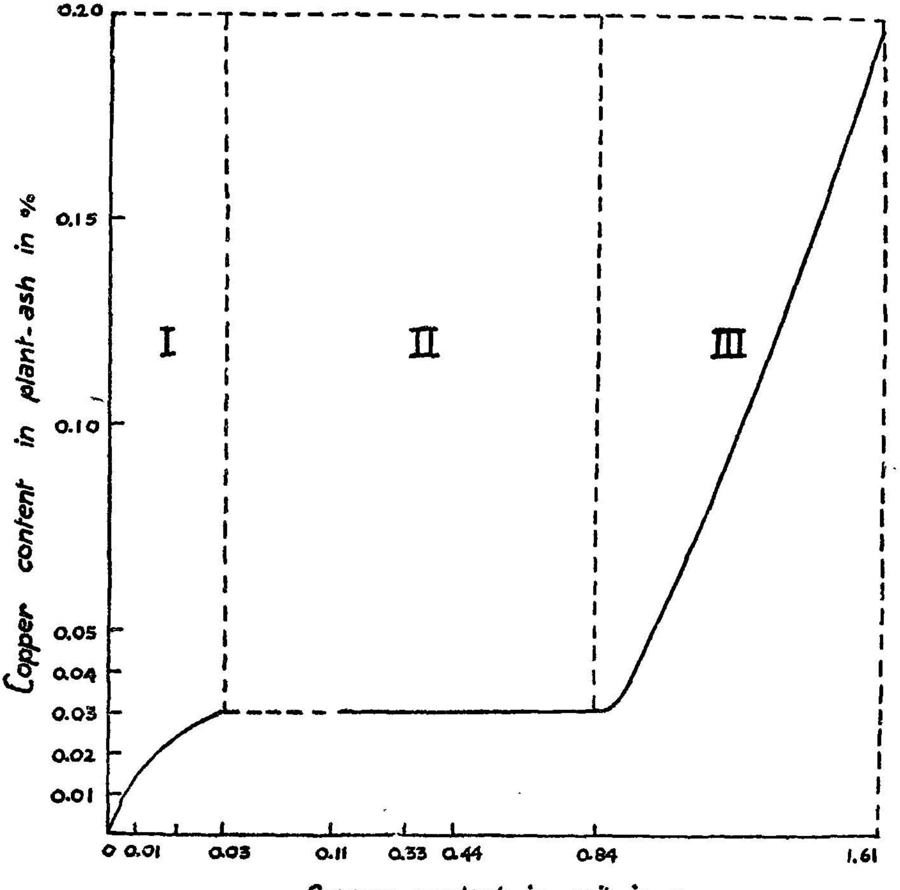
PLATE 44



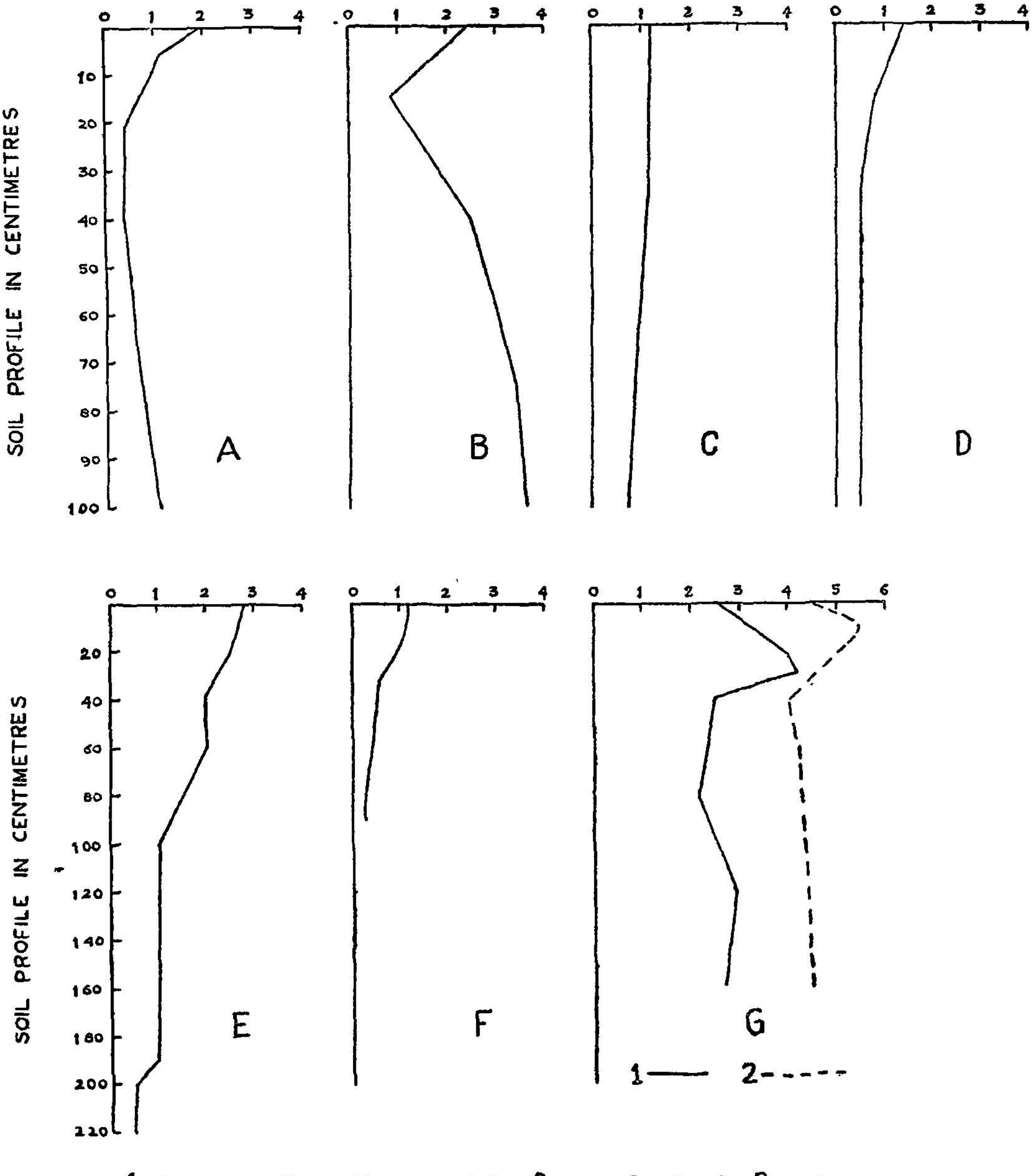
RELATION BETWEEN COPPER CONTENT IN SOIL AND IN PLANT ASH OF MATTHIOLA INCANA

I- no change in external look of plant; II- plant growth retarded, leaves become yellow, cluster together, dry and fall; III- plant is poisoned and dries.

AFTER TKALICH, S.M.

PLATE 45

DISTRIBUTION OF COPPER IN PROFILES OF DIFFERENT SOILS



A- turf podzol; B- greyish peat-podzol; C- grey forest soil; D- serozem; E- chernozem; F- chestnut soil; G- deep columnar solonetz; (1); meadow solonchak with chlorides and sulphates. (2).

After: LAKIN

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APPLICATION OF GEOPHYSICAL METHODS TO EXPLORATION FOR COPPER-ORE IN INDIA.

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(With Plates 46-54)

ABSTRACT

Electrical and electromagnetic methods, supplemented by magnetic observations, are generally the most useful in the search for copper deposits. In regions which are not easily accessible preliminary aerial electro-magnetic and magnetic surveys may prove useful.

The geophysical response is dependent on a number of factors such as the mode of occurrence of the ore minerals, the structural disposition of the rock formations, their lithological characteristics, terrain conditions etc. The nature of the response under varying geological conditions has been discussed.

Geophysical surveys for copper-ore have been carried out by the Geological Survey of India in almost all the well known copper belts in the country. Short accounts of the results of these investigations are given in this paper.

INTRODUCTION

In recent years, there has been considerable intensification of efforts in India for the exploration and development of the resources of copper and other base metals in which the country is particularly deficient.

In conjunction with detailed geological mapping supplemented by geochemical tests, intensive geophysical investigations have been conducted both in known major copper belts for the location of possible additional large deposits, as also in other new areas where geophysical investigations are considered feasible and warranted on the basis of available geological evidence.

Geophysical investigations employing electrical, magnetic and

electro-magnetic methods have been conducted in the well known copper belts of Khetri in Rajasthan and Singhbhum in Bihar as also in Dariba (Rajasthan), Ambaji area (Gujarat), the Gani-Kalava, Garimanipenta and Agnigundala areas of Andhra Pradesh, Mamandur area in Madras, Kalyadi area of Mysore and Sleemanabad area in Madhya Pradesh.

SCOPE OF APPLICATION AND CHOICE OF GEOPHYSICAL METHODS

Of all the ores of copper, chalcopyrite, the principal commercial ore of copper is the most responsive to geophysical methods of exploration. This ore mineral is a good electrical conductor (with a specific resistance of the order of 0.1 to 0.2 ohm—cm. (Heiland) and as it gives rise to the well known phenomenon of self (spontaneous) potential effects whether it occurs in association with pyrites and other sulphides or not, it is readily amenable to exploration by the self-potential, electrical resistivity and electro-magnetic (galvanic as well as inductive) methods. Geophysical location of metallic ores in general is either direct by detecting the distinctive property *i.e.* contrast in the physical parameter which any particular method uses, or indirect (structural), by investigating and mapping the sub-surface structures which control mineralisation. Of the four major methods of geophysical exploration *viz.* gravity, magnetic, electrical and seismic, based respectively on the physical properties of density, magnetic susceptibility, electrical conductivity or its reciprocal resistivity and elastic co-efficients (which determines the seismic wave velocity) respectively of rocks, the geo-electric and magnetic methods find the widest application in the exploration for metallic ores. The gravity method is occasionally used with great advantage for the location of commercially workable ore bodies of heavy metals like lead, chromium (and also manganese under favourable terrain and sub-surface geological conditions) affording an appreciable density contrast between the ore body and the surrounding rocks, but has on the whole relatively limited application because of the fact that the gravity anomalies produced even by large commercially workable ore bodies of such heavy metals are of a small magnitude, generally of less than half a milligal. Where terrain conditions are disturbed, which is often the case, interpretation of such small ano-

malies in terms of the presence or otherwise of the ore becomes difficult and uncertain, as quite often the anomalies caused by such terrain effects may be larger than the anomaly actually produced by the ore body. Of late, however, the gravity method is finding increasing use in the exploration of ores of heavy metals owing to improved techniques of mathematical interpretation.

Seismic methods which are mostly employed for the investigation of stratified formations, have even more limited scope than the gravity method in the exploration for metallic ores, because of the smallness of the ore bodies in relation to the dimensions of the seismic profiles to be employed.

Thus the geo-electric and magnetic (in that order) are the best suited geophysical methods for exploration of metallic ores. Even in such cases, the choice of any particular method will be governed by the type of ore, its mode of occurrence, the geological (structural) conditions and to some extent the origin of the ore *i.e.* whether the ore is of the magmatic differentiation type occurring in intrusive rocks ; dynamo-metamorphic deposits formed as a result of chemical transformation of rock substances and concentration by diastrophic forces ; solution deposits, both autogenetic and heterogenetic or mechanical concentration deposits as in gravels, conglomerates etc. (Lindgren's classification).

The application of geo-electrical and magnetic methods for exploration of copper-ores (mainly sulphides) is briefly discussed indicating the conditions under which these methods may be applied successfully.

ELECTRICAL METHODS

The geo-electrical methods which are more diversified than any of the other geophysical methods are best suited for metallic ores which are good electrical conductors such as sulphide ores of iron, copper etc. The application of the various electrical methods for such ores are as follows :—

Self-Potential Methods

Certain sulphide ore bodies, such as pyrite, pyrrhotite and chal-

copyrite under favourable conditions give rise to pronounced natural electrical field in the sub-surface due to spontaneous electrochemical activity. The generally accepted explanation for the phenomenon is that the upper portion of a sulphide ore body producing spontaneous polarisation effects is a zone of oxidation relative to the lower portion as would be the case if the upper portion is in the zone of aeration above the water table with its lower end beneath the water table. This differential oxidation at the two ends would cause different solution pressures in the upper and lower portions in consequence of which a potential difference is established between the two ends. An electric current flows within the ore body from its upper to the lower end, the return current in the sub-surface outside the ore body flowing upward to the ground surface. A potential anomaly is indicated on the ground surface above the ore body generally in the form of a pronounced closed negative centre. Strong anomalies of the order of 500 to 1000 millivolts are sometimes encountered. More recently Sato and Mooney (1960) have suggested that the spontaneous polarisation current may be produced by separate but simultaneous reductions of oxidising agents near the surface and oxidation of reducing agents at depth depending upon differences in oxidation potential of groundwater at different depths. They hold that the ore body serves as a conductor in transferring electrons from the reducing agents to the oxidising agents. According to them the existence of a regular water table is not a specific criterion for electrochemical mechanism for self-potentials ; nor is the existence of continuous band of mineralisation extending above and below the water table is necessary although the water table provides a very favourable condition of a large and abrupt contrast.

It may be mentioned that while the transmission of current within the sulphide body is mostly by metallic conduction, the mode of transmission in the surrounding formation is. largely electrolytic or ionic. This would mean that the potential gradient and magnitude of the anomaly as observed on the ground surface would be governed by the nature of the surrounding rocks and the overburden. If sizeable ore bodies occur in schists or foliated rocks with sufficient moisture content natural currents carried by the ore body find a ready passage through the formations outside the body affording favourable conditions for detection on the ground surface by potential measurements. If, on the other hand, the sulphide ore occurs as disseminations in a fine-grain-

ed tight and compact rock, even if the dissemination in the aggregate is extensive and the deposit economically workable, the natural currents produced tend to be very weak and feeble due to lack of continuity and difficulty in transmission in the compact and resistive rock formation in which the dissemination occurs. Again if the upper layers of the overburden are fairly resistive as in the case of dry sandy overburden, strong surface potential gradients are obtained in the vicinity of the ore body whereas if the overburden is conductive as in the case of a clayey overburden, the magnitude of the S. P. anomaly as well as surface potential gradient tends to become weak and poorly defined, the highly conductive overburden masking the effects of the conductive ore body.

Besides sulphide ores such as pyrite, chalcopyrite and pyrrhotite, bodies of graphite, anthracite coal and magnetite also produce strong self-potential anomalies.

The ground potentials are measured usually with a calibrated potentiometer of high precision used in conjunction with non-polarisable electrodes, at regular intervals of 10 to 15 metres along traverses 50 to 60 metres apart (for detailed surveys) across the supposod strike of the formation or the ore body. An equipotential map is prepared, showing the sub-surface sulphide ore body as a closed negative potential centre on the ground surface above the ore body.

In case the sulphide ore body does not produce natural earth currents or self-potentials as for instance, galena, the surface potential or equipotential line-methods can be employed, wherein current from an external source is impressed into the ground through a pair of grounded electrodes (point or linear). The presence of a buried conductor is indicated by the distortion in the normal current and potential distribution to be expected from a homogenous ground. The equipotential lines are repelled and wander away from the conductor, whereas the current filaments are drawn towards it and these distortions are brought out in the surface equipotential map. Either direct or alternating current can be used for energising the ground ; if direct current is used, non-polarisable electrodes will have to be employed for measuring the potentials. Headphones with suitable audio-amplifiers are used as null indicator when alternating current (usually with frequencies of 500 to 1,000 cycles per second), is used.

Resistivity Methods

Surface electrical resistivity methods are employed in conjunction with self-potential methods for the location of conducting ores such as chalcopyrite which are brought out as conductive anomalies in the surface apparent resistivity profiles or equi-resistivity contour maps. Although the resistivity methods are particularly well adopted for the investigation of horizontally stratified formations, and have limitations for locating vertically disposed or steeply dipping ore bodies with limited lateral extent, especially when such ore bodies occur at relatively large depths, these methods can be used with advantage under favourable conditions for the location of conductive ore bodies occurring at shallow depths of the order of 30 to 60 m. such as when the ore mineralisation is associated with fault planes, contact zones etc. The lateral variation in the sub-surface resistivity is investigated by the method of resistivity traversing with equal electrode separations as in the Wenner arrangement, or with asymmetrical electrode separations with the spacing between the potential electrodes adjusted according to necessity, especially when investigating buried bodies or structural features with limited lateral extent. The electrode system as a whole is continually moved along a traverse across the structure or the strike of the ore body by constant intervals of distance, and the apparent resistivity measurements are repeated with different electrode spacings corresponding to varying depths investigation of the subsurface resistivity.

A commonly used resistivity apparatus is the Gish Rooney type of potentiometer which has separate current and potential circuits incorporated in it. Commutated direct current is impressed into the ground and is measured by means of a milli-ammeter incorporated in the current circuit. The potential difference is measured over a calibrate slide wire used in conjunction with an auxiliary potentiometer to balance out the natural earth potentials in the ground. A sensitive galvanometer is provided in the potentiometer circuit. Where as the current is passed into the ground through grounded copper electrodes, non-polarisable electrodes, usually of the Cu—$CuSO_4$ type, are used as potential electrodes to eliminate the effects of polarisation at the potential electrodes. A double commutator is provided to obviate the effects

of stray currents and leakages from the current to the potential circuit.

Potential-Drop Ratio Methods

In this method the potential drop in two equal successive intervals along a traverse is measured with a special type of A.C. Wheatstone bridge using three metal stakes. This method is particularly useful for investigating formation boundaries, faults etc. controlling mineralisation. The two outer electrodes are connected to the two arms of the bridge each of which includes a resistor and a capacitor in series or parallel with a centre tap between these two arms connected to the middle electrode. The two ground intervals constitute the two other arms of the bridge. Alternating current of frequency 500 to 1000 cycles per second is impressed into the ground and a headphone with an amplifier is used as a null indicator. The whole arrangement is moved across the formation boundary or fault to be investigated.

Electromagnetic Methods

The electromagnetic methods are being increasingly used in the exploration of metallic ores. The methods have some advantages, especially in hilly terrain where difficulties in securing satisfactory electrical contacts with grounded electrodes are often encountered. This difficulty is obviated in the electromagnetic inductive methods where the ground is energised inductively by means of insulated loops or coils. Also the response of a buried conductor with limited lateral extent can sometimes be obtained with greater resolution than by the other electrical methods previously described.

When alternating current is passed into the ground conductively or inductively, good conductors in the sub-surface produce a secondary magnetic field as a result of the current induced in them. This secondary field causes distortions in the primary field. The resultant field is studied by means of receiving coils suitably disposed. The distortions of the primary field by the secondary field is dependent on a number of factors such as the depth and attitude of the ore body, the

electrical constants of the ore body and the surrounding rocks as also *the nature of the electrical excitation.*

In the electromagnetic galvanic methods, alternating current of frequency ranging from 200 to 1,000 cycles is impressed into the ground conductively through point or line electrodes ; line electrodes are laid out at right angles to the strike of the structure controlling mineralisation or the ore body and if point electrodes are used they are fixed parallel to the strike. Various arrangements can be used to determine and study the resultant field, but all of them employ some form of receiving coil or coils. In one procedure the relation of the field intensity and their phase differences at successive points on the ground are measured by means of dual coil arrangements and ratiometer bridges.

The inductive method of electromagnetic prospecting is more commonly used these days in the exploration of conductive metallic ores. In this method the current is introduced into the ground inductively by means of insulated loops or coils. No ground contact is thus necessary for energising the ground, which is a great advantage. The primary or transmitting coil used for energising the ground consists of several turns of insulated wire carrying generally a strong alternating current with frequency in the range of 200 to 210 cycles per second. Higher frequencies have the disadvantage of limited depth penetration due to rapid attenuation within the ground. Lower frequencies have the advantage of greater penetration but, on the other hand, suffer from the disadvantage of reducing the strength of the induced currents and, therefore, the secondary field. The primary (excitation) coil can be used vertically or horizontally according as the ore body is disposed vertically or horizontally, to obtain the maximum effect of the buried conductor. The receiving coil usually consists of several hundred turn of wire.

In the electromagnetic inductive method of prospecting, the resultant field is studied either in terms of its direction (dip angle) or in terms of its amplitude and phase variations. The first method involving dip angle measurements is used for reconnaissance investigations and is particularly useful in the location of buried contact zones, faults etc. Various arrangements for the disposition of the transmitter and receiver are employed in making these angle measure-

ments. In the 'in-line' method, the transmitter and receiver are moved along the traverse across the supposed strike of the conductor or structure with a constant separation of 60 or 120 m. (200 or 400 ft.) between the transmitter and receiver. In the 'broadside' arrangement, the transmitter and receiver are moved along parallel lines across the presumed strike. In the 'set-up' method, used for tracing the extension of known ore bodies, the transmitter is set up over the conductor and for each observation the transmitter is so oriented as to have its plane passing through the receiver position. The receiver is moved along traverses at right angles to the supposed strike of the conductor. The data are plotted as dip angle profiles along the traverses.

The second method involving phase measurements gives more detailed information and is more diagnostic of sub-surface conductors than the first. This method is based on the fact that the secondary electromagnetic field produced by a buried conductor is made up of an in-phase and out-of-phase component and as such the e.m. anomalies can be measured in terms of the changes in the magnitude and phase of the total or resultant field.

Electromagnetic inductive prospecting units are available in portable types suitable for convenient operation even over rugged and hilly terrain. The transmitter and receiver coils are in the form of portable iron-cored or ferrite-cored solenoids. The alternating current for the transmitter is generally derived from an electronic osciliator and has generally a frequency in the range of 500 to 2,000 c.p.s. The unit permits observations at two frequencies of the transmitter.

The transmitting and receiving coils are placed with their axes vertical so that the plane of the two coils is horizontal. They are kept at a fixed distance with the aid of a connecting or reference cable generally of 60 to 80 m. in length. The effective depth of penetration is governed by the transmitter-receiver separation and is estimated roughly to be one half of the separation. The presence of a conducting ore body in the range of the primary field of the transmitter produces a secondary electromagnetic field which along with the primary field is picked up by the receiver coil and fed to a compensator which also receives a fraction of the primary current from a comparator coil fixed in the strong field of the transmitter wire loop. The two signals are

compensated or annulled against each other by adjustment of the compensator as indicated by the headphone or stethophone which receives the amplified output from the compensator. The anomaly field affecting the receiver coil is measured in two dials giving the in-phase and out-of-phase components as percentages of the primary or normal field. The transmitter-receiver arrangement is moved along a traverse across the supposed strike of the conductor. In the absence of any conductor there will not be any out-of-phase component and the normal component of the in-phase field for any coil separation can be determined, thus permitting the anomaly values to be plotted as percentage changes from the total field. The nature and shape of the in-phase and out-of-phase anomalies will generally be the same, but their magnitudes will depend on the size, relative conductivity of the ore body and the frequency employed. The in-phase values are appreciably influenced by terrain effects and the use of two frequencies provides a means for estimating the relative conductivity by utilising the two out-of-phase magnitudes.

Induced Polarisation Methods

For the exploration of conducting metallic sulphides which occur as disseminations in tight, fine-grained compact host rocks, the normal ground resistivity and electromagnetic methods have serious limitations. In such cases, the Induced Polarisation method may afford distinct advantages.

The Induced Polarisation method is based on the electrochemical polarisation, also known as over-voltage effect which occurs when electrical current is passed through a rock containing conducting metallic minerals such as sulphides of copper, etc. The polarisation occurs over the metallic interfaces within an electrolyte and is believed to depend on chemical energies required by the ions to maintain the flow of current by shedding or receiving an electron from metallic surfaces, the energy stored in such reaction being similar to the energy stored in a charged condenser.

Both interrupted direct current and alternating current can be used for induced polarisation measurements. D. C. energy can be impressed into the ground from a petrol engine driven alternator through voltage control device, rectifier and switching relays. The

ground is energised by direct current for a specific duration depending on the ground conditions. On switching off the current, the resulting induced polarisation voltage is picked up by potential electrodes and fed into a suitable recorder which measures the magnitude of the energising current, the voltage picked up by the potential electrodes during the passage of the current and the nature and mode of decay voltage on switching off the energising current against a standard voltage. The polarisability of the ground and the nature and distribution of the conducting minerals will determine the induced polarisation voltage and its decay.

If alternating current is used to energise the ground, the induced polarisation would depend on the electrical impedance of the system and the frequency of the alternating current. The apparent resistivity of the ground for a given set-up of the current and potential electrodes is determined for a number of frequencies of the alternating current and if there be any appreciable variation in the apparent resistivity values for different frequencies, induced polarisation is inferred. For the field measurements using alternating current, the electrical energy from a motor driven generator drives a transmitter which creates currents at a number of frequencies to be impressed into the ground. The receiver consists of a stable and sensitive potentiometer.

The induced polarisation is reported to be sensitive to small traces of conducting sulphides and a sulphide content of even one or two per cent. is stated to produce measureable difference in the apparent resistivity by varying the frequency of the energising current. Thus large polarisation effects are possible when appreciable amount of even disseminated sulphides are present.

It can be realised that some moisture should be present in association with the conducting metallic sulphides to produce induced polarisation. Another advantage claimed for this method is that even ore bodies at large depths of the order of 160 or 300 m. can be detected by using large spreads. Apart from this advantage in locating deeply buried ore bodies and zones of disseminated sulphides, this method is also useful in distinguishing conductive zones due to electrolytes from metallic mineral conductors, which is not possible by using the other electrical methods.

Drillhole Electromagnetic Exploration

The technique of drillhole electromagnetic surveying is now-a-days adopted for deeper exploration when sufficient number of deep diamond drillholes are available in the area under investigation, as it helps substantially in reducing the cost of exploratory drilling in a mineralised area. The basic principle of this method is the same as in the case of surface electromagnetic methods. A common procedure employed is to place the transmitting coil on the ground surface above the borehole. The receiving coil is lowered into the drillhole by regular intervals of 50 to 30 m. with the plane of the coil at right angles to the hole. When the transmitting coil is placed above the hole in a vertical plane, no signal will be generated in the receiving coil. If a conductor such as a sulphide ore body is present near the borehole laterally, the primary field from the transmitter produces induced currents within the ore body resulting in a secondary field the magnitude and direction of which will depend on the size, shape and location of the body in relation to the hole. This secondary field will have a vertical component which will produce a signal in the receiver. The transmitting coil may now be tilted from its vertical position suitably so that the vertical component in the transmitting coil annuls the vertical component in the receiver coil. The angle of tilt of the transmitter required to produce this null is governed by the size and shape of the ore body, and its distance from the borehole.

By making borehole e.m. measurements in this manner the lateral disposition of a known mineralised zone occurring even at relatively large depths of 300 m. or more can be investigated provided sufficient number of deep boreholes are available. The range of detection of an ore body away from the borehole in which the measurements may be made is presumed to be of the order of 130 to 150 m.

This method can be adapted for observations in vertical as well as inclined drillholes.

Airborne Electromagnetic Prospecting

Now-a-days airborne electromagnetic surveys are quite frequently conducted for the exploration of metallic ores, especially con-

ducting sulphides, on a reconnaissance basis in inaccessible areas and over rugged and hilly terrain where ground surveys may be slow, difficult and expensive. The principles of this technique are the same as in surface electromagnetic prospecting. The transmitting and receiving coils are mounted in an aircraft which carries out the flight lines on a regular pattern with lines about a quarter mile apart, flying at an altitude of 60 m, to 150 m. (200 to 500 ft.) from the ground surface. The e.m. system as usual measures the in-phaseand out-of-phase componentst of the secondary electromagnetic field caused by the sub-surfac conductors by induction by primary field of the transmitter at a frequency of the order of 200 to 500 cycles per second. In one form of modern airborne e.m. system, the transmitter and receiver coils are mounted on each wing tip of the aircraft in a coplanar vertical configuration separated by a distance of less than 30 m. Generally an airborne magnetic system and a scintillometer are also installed in the same aircraft so that electromagnetic, magnetic and scintillometric measurements can be made concurrently in the course of the same survey flights at economic costs.

Airborne electromagnetic surveys in conjunction with airborne magnetometric measurements are quite useful in the exploration for metallic minerals on a preliminary, rapid reconnaissance basis for a rough delineation of mineralised zones, especially over difficult terrain and hilly or mountainous regions and for the demarcation of specific areas of promise which can subsequently be surveyed in detail by ground geophysical methods. But over steep hills with marked relief, even airborne electromagnetic and magnetic measurements for metallic minerals may be impracticable because of difficulties in manouvering the flights in-as-much-as the aircraft has to fly at low altitudes with relatively close flight lines.

Magnetic Methods

The magnetic methods are usually employed in the exploration of metallic ores in conjunction with electrical methods to supplement the latter, in view of the fact that quite frequently, ore bodies such as sulphide ores of copper, iron etc. are associated with magnetic minerals such as magnetite and pyrrhotite, which occurring even in relatively small quantities produce strong magnetic anomalies on the

surface. The magnetic method also quite often proves useful in an indirect manner by affording structural information which aids in the location of the ore, as for instance, when magnetite occurs in association with certain structural trends or features such as faults, contact zones, shear zones, intrusives etc. which may control and determine the disposition of the ore mineralisation. The magnetic method has also been used succesfully in the exploration for native copper in lava flows, as for instance, in the Lake Superior region, U. S. A. where native copper occurs in a series of ancient lava flows and conglomerates. In this region the magnetic method proved successful in an indirect manner by tracing and mapping the sub-outcrops, faults etc.

Ground magnetic surveys are mostly conducted by Schmidt-Askania type of magnetometers (vertical and horizontal). These instruments have a high precision with sensitivity of the order of 10 gammas.

The airborne magnetometer, which in the post-war period has been used extensively for preliminary studies of basement topography in oil exploration, is also being increasingly used for prospecting for magnetic minerals and ore bodies, especially in inaccessible areas for a broad delineation of the mineralised zones preliminary to further detailed surveys by ground geophysical methods. The sensitivity of the airborne magnetometer which measures variations in the total intensity of the earth's magnetic field (rather than the vertical and horizontal components as is the case of the ground magnetometers) is necessarily higher than that of a ground magnetometer and is of the order of one or two gammas. While the flights for aeromagnetic surveys in oil exploration are usually made at heights of 900 to 1,200 metres (3,000—4,000 ft.) from the ground surface, in exploration for ore bodies the flights have to be carried out at relatively small heights of 90 to 150 m. (300 to 500 ft.) with flight lines every 400 m.

Some results of the application of geophysical methods

Geophysical investigations have been conducted by the Geological Survey of India over many areas during the past few years; the results of these investigations are given briefly below :—

Khetri copper belt, Rajasthan : Detailed electrical surveys employing the self-potential, resistivity and electromagnetic methods have been conducted in this well known copper belt in a systematic manner.

This belt stretches in a roughly N. W.—S. E. direction from Singhana in the north-east through Babai in the south-west and beyond to Kishorepura, Satkui and Dhanaota where recent geological and geophysical surveys have indicated significant possibilities of copper occurrences. The rock formations in this belt belong to the Alwar and Ajabgarh series which have been thrown into plunging folds. Major faults and shear zones control the mineralisation.

The ore minerals generally consist of chalcopyrite, pyrite, pyrrhotite and malachite occurring as stringers in the slates, schists and associated quartzites and dolomitic marble. In view of the association of some magnetite with the ore minerals, the magnetic method was also employed. So far an area of roughly 125 sq. km. (50 sq. miles) has been covered by these geophysical surveys.

In the Singhana-Banawas area, mineralisation is seen over the western flank of the dolomitic and marble hill with another zone of mineralisation in the Banawas mine and its eastern edge.

A number of strong potential anomalies varying in magnitude from-100 to-250 millivolts have been outlined in the Singhana-Banawas area and many of them are corroborated by strong magnetic and resistivity (conductive) anomalies. An anomaly zone extending over a distance of 300 m. (1,000 ft.) in the N.N.E.-S.S.W. direction to the south of Singhana has been outlined in this part, with some 14 strong self-potential centres. The axes of these S. P. anomalies as also those of the resistivity (conductive) and magnetic anomalies have been shown with some of the drilling sites in plate 46. Typical self-potential, magnetic and resistivity profiles obtained in the Singhana-Banawas area are presented in Plate 47.

Four of the indications in the Singhana-Banawas area have been tested by exploratory drilling by the Geological Survey of India and the results of the boreholes KBH 7 and 9 (Pl. 46) are quite encouraging.

In borehole KBH 7 taken to an inclined depth of 171 m. (560 ft.), a continuous mineralised zone with an average copper content of 1.6 per cent was intersected between inclined depths of 90 to 97m. (297 and 318 ft.). This zone is vertically below the resistivity axis. In KBH 8 taken to a depth of 139 m. (456 ft. inclined), a 3 6 metre (12 ft.) magnetite horizon was met with at an inclined depth of 80 m. (262 ft.) beyond which pyrrhotite and arsenopyrite were encountered.

In borehole KBH 9 very encouraging results have been obtained. The main lode extends over an inclined depth of 84 m. (278 ft.) within which a number of small sub-zones exist, the copper content varying from 1 to 2.65 per cent.

In the Babai-Paprona area further to the south-west, a number of pronounced self-potential, resistivity (conductive) and electromagnetic anomalies were outlined over an extended zone of about 2,440 m. (8,000 ft.) in width. Test drilling carried out in this region over some of the strong anomalies struck only graphitic schists and carbonaceous phyllites at depths of 15.2 to 26 m. (50 to 85 ft.) from the ground surface.

Further to the south and south-west of Babai in the Kishorepura-Satkui-Dhanaota area a number of strong self-potential anomalies supported at many places by magnetic and electromagnetic anomalies have been outlined in association with the shear zone. These indications appear to be promising.

Singhbhum copper belt, Bihar : The well known Singhbhum copper belt in Bihar stretches over a length of 115 km. (70 miles) in a N.W.—S.E. direction roughly from Sini to Khejurdari including areas of Rajdaha, Roam, Ramachandrapahar, Rakha, Kendadih, Surda, Mosaboni, Badia and Churidhi.

The rock formations in this belt consist of quartzites, chlorites and talc-schists, granites, dolerites and epidiorites. The region is characterised by a prominent shear zone which is presumed to control largely the mineralisation. Extensive old workings exist in this belt. The important copper deposits at present worked are at Mosaboni.

The deposits at Rakha and Surda are considered to be very promising. The ore consists of deeply dipping lodes and stringers with chalcopyrite and pyrrhotite with some magnetite. The mineralisation in the Mosaboni area is within soda-granite while it is in quartzites in the Rakha-Roam area. In the Rajdah-Ramachandrapahar region it is in the chlorite-schists.

Detailed geophysical surveys have been conducted over an area of about 75 sq. km. (70 sq. miles) including the areas of Baharagora, Surda, Rakha, Rajdah, Dudra, Naraianpur, Lakhodih aud south of Mosaboni. Some pronounced self-potential-cum-resistivity (conductive) indications supported by magnetic anomalies have been outlined in the Rajdaha-Surda area with a few indications also in the Roam-Siddesher region of this belt (pl. 48 and 49). The magnitude of the S. P. anomalies varies from-200 to-400 millivolts.

Recent test drilling conducted by the Geological Survey of India in the Roam area is reported to have yielded encouraging results. A mineralised zone containing copper has been struck over a thickness of six metres (20 ft.) with an average copper content of two per cent.

Gani-Kalava and Agnigundala areas, Andhra Pradesh (Pl. 50) : In the Gani-Kalava copper belt of Andhra Pradesh, the formation belong to the Lower Cuddapah and Kurnool systems. Trap flows and quartz reefs occur interposed in the Tadpatri shales of Pre-Cambrian age and limestones. Several old workings exist in a belt located in the contact zone of the Tadpatri shales and traps. Disseminations of copper pyrites are seen in the contact zone. The area is characterised by shear faults and drag folds.

An area of roughly 50 sq. km. (20 sq. miles) has been geophysically surveyed in this belt employing the self-potential, resistivity and magnetic methods. Some twelve strong self-potential centres varying in magnitude from -300 to -600 millivolts were outlined in this region and many of these have been corroborated by pronounced resistivity (conductive) anomalies. Four of the pronounced indications in the Kalava area have been recently tested by exploratory drilling. These, however, revealed only carbonaceous shales and traps with sparse disseminations of pyrite. A borehole put down over one of the strong

anomalies in the Gani area also encountered only carbonaceous shales which, therefore, appear to be the cause of the observed geophysical anomalies in this region.

In the Agnigundala area electrical and magnetic surveys have been conducted over the Peddakonda and Dhukonda hills. The rock formations in this area consist of shales, phyllites, Cumbum slates, micaceous schists and quartzites of Upper Cuddapah age associated with limestones and dolomites and granites and gneisses of Archaean age. The rock formations are considerably folded and faulted with the mineralisation confined to the quartzites and slaty phyllites. There are a number of old workings near the hill slopes located along the phyllite-quartzite contact. The quartzites show malachite and azurite encrustations whereas galena, pyrite, chalcopyrite and malachite disseminations are seen in discontinuous form in the quartz veins.

A few feeble self-potential anomalies of the order of -50 millivolts have been indicated in the Dhukonda area in the vicinity of the old workings. The feeble nature of the anomalies must be ascribed to the hard, compact and tight host rocks and does not necessarily suggest the absence of significant mineralisation. Some appreciable magnetic anomalies have been indicated over the iron rich shales.

Mamandur area, South Arcot district, Madras (*Pl. 51*) : Electrical and magnetic investigations have been conducted in the Mamandur, Toluvantongal and Odiyandal areas in Kallkurchi *taluk* of South Arcot district, Madras.

The mineralisation occurs as disseminations in tight, compact rocks viz., amphibolites and hornblende-granulite along a sheared contact zone in Mamandur, while in the Toluvantongal and Odiyandal areas the mineralisation is in the granite gneiss. The ore minerals encountered include chalcopyrite, sphalerite, galena, azurite and malachite.

Some feeble anomalies have been outlined in the Mamandur area over the mineralised zone with a magnitude of the order of -30 to -50 millivolts. The low magnitude of the anomaly is essentially due to the tight, massive and compact nature of the host rock and not due to absence of significant ore mineralisation. The anomalies have a striking

pattern and are suggestive of good mineralisation and as such deserve test drilling which has since been conducted. An angle hole put down in the northern portion of the mineralised zone is reported to have encountered a rich lode of roughly three meters (9 ft.) in width, having an average assay value of 0. 34 to 0. 4 per cent. copper, 6. 26 to 7. 28 per cent. zinc and 1. 35 to 15. 46 per cent. lead. Another hole encountered a chalcopyrite rich mineralised zone roughly 13 m. (43 ft.) in width and associated with galena and sphalerite.

In the Toluvantongal area also some feeble self-potential anomalies were indicated, but no anomalies were obtained in the Odiyandal area.

Kalyadi area, Hassan district, Mysore (Pl. 52 and 53) : In the Kalyadi area of Mysore, the mineralisation occurs in a narrow strip of Dharwar metamorphics consisting of steatite-schists, quartzites, quartz-schists, sericite-schists, phyllites and amphibolites associated with peninsular suite of granites and granite gneisses. Old workings exist in this area where the mineralisation is localised by the drag folds in the quartzites. The ore mineralisation is noticed along the eastern limb of a minor synclinal fold at the contact of quartzites and quartzite-schists on the one hand and the steatite-schists on the other, in the form of malachite and azurite encrustations with some pyrite and chalcopyrite in the debris.

The self-potential measurements in the area indicated some feeble self-potential anomalies along the ridge with a magnitude of the order of -20 to -60 millivolts. Some magnetic anomalies were also outlined associated with the steatite-schists, magnetite-quartzite and dolerite dykes. The self-potential anomalies are significant in their pattern, notwithstanding their low magnitude which has again to be attributed to the tight and compact nature of the host rocks and possible association of lead and zinc minerals as in the Mamandur area. Test drilling carried out by the Geological Survey of India in co-operation with the Mysore Government has yielded encouraging results.

Ambaji area, Banaskhanta district, Gujarat (Pl. 54) : Electrical (self-potential and resistivity), electro-magnetic and magnetic investigations

were conducted in the Ambaji area in the Banaskhanta district of Gujarat. The area geophysically surveyed falls within the region of phyllites and mica-schists of the Ajabgarh series (Delhi system) with outcrops of Erinpura granites occurring to the west and south, and Ajabgarh gneisses and limestones to the east. Old copper workings exist in the Ambaji area along the summit of a ridge running parallel to the Ambaji-Abu road and are located in crumpled biotite-schists, talc-schists and rusty quartzite with a good amount of quartz veining. Malachite and azurite are noticeable in the debris with occasional specks of pyrite and chalcopyrite. Exposures of basic intrusives consisting of epidiorite are met with in the surveyed as well as the adjoining areas.

Nine self-potential anomalies have so far been outlined in this area, the stronger ones of which have magnitudes varying from -100 to -300 millivolts. A major self-potential anomaly zone corroborated by pronounced magnetic and electro-magnetic (in-phase and out-of-phase) anomalies has been outlined near the village of Omli-Ka-Mala. This zone, however, falls entirely over a basic rock exposure with no surface evidence of mineralisation. The computed depth to the causative body on the basis of the self-potential and electro-magnetic anomalies is of the order of 11 metres. It is doubtful if this anomaly is due to copper mineralisation. Test drilling will establish the cause and nature of these anomalies.

Besides the areas mentioned above geophysical investigations for copper-ore have also been conducted in the Garimanipenta area of Andhra Pradesh, in the Dariba area of Rajasthan and Sleemanabad area of Madhya Pradesh.

In Garimanipenta, rock exposures are scarce, the ground being being mostly covered by sandy loam and clays. The country rock is presumably a gneissic complex, cansisting of schistose, foliated and hornblendic rocks.

The self-potential and resistivity indications obtained in this area have been attributed to highly conducting surface clays which incidentally render the geo-electrical methods unsuitable for exploration of sulphide ores in this area.

In the Dariba area in Alwar district of Rajasthan also a number of old workings exist. The rock formations in this area belong to the pre-Delhis (gneisses and biotite-schists), Raialos (marbles and amphibolites) and Alwar series (phyllites, conglomerates and quartzites) of the Delhi system. Amphibolites are noticed on the south-western flanks of the Khoh-Dariba range while phyllites occur on the north-eastern flanks. Over the summit and upper flanks of the range grits and quartzites occur. The Baldeogarh anticline is the major structural feature in this area with a number of steeply dipping faults. The mineralisation is mainly along the fault planes as in the Dariba mine area, where it is within the phyllites. The ore minerals encountered are chalcopyrite, pyrite and pyrrhotite in the fissures and joints in the fault zones.

Geophysical surveys employing the self-potential and magnetic methods were conducted in the Dariba, Khoh and adjoining areas. Some significant self-potential anomalies were outlined in the Dariba-Khoh areas in four anomaly zones. Exploratory drilling carried out subsequently by the Indian Bureau of Mines struck copper lodes in two of these zones namely the Dariba mine and Dariba *nala* areas.

In the Sleemanabad area where some surface evidence exists in the from of mineralised quartz veins traversing the schistose rocks, some limited electrical and magnetic surveys have been conducted but no significant indications have been obtained.

CONCLUSIONS AND FUTURE PROGRAMME OF WORK

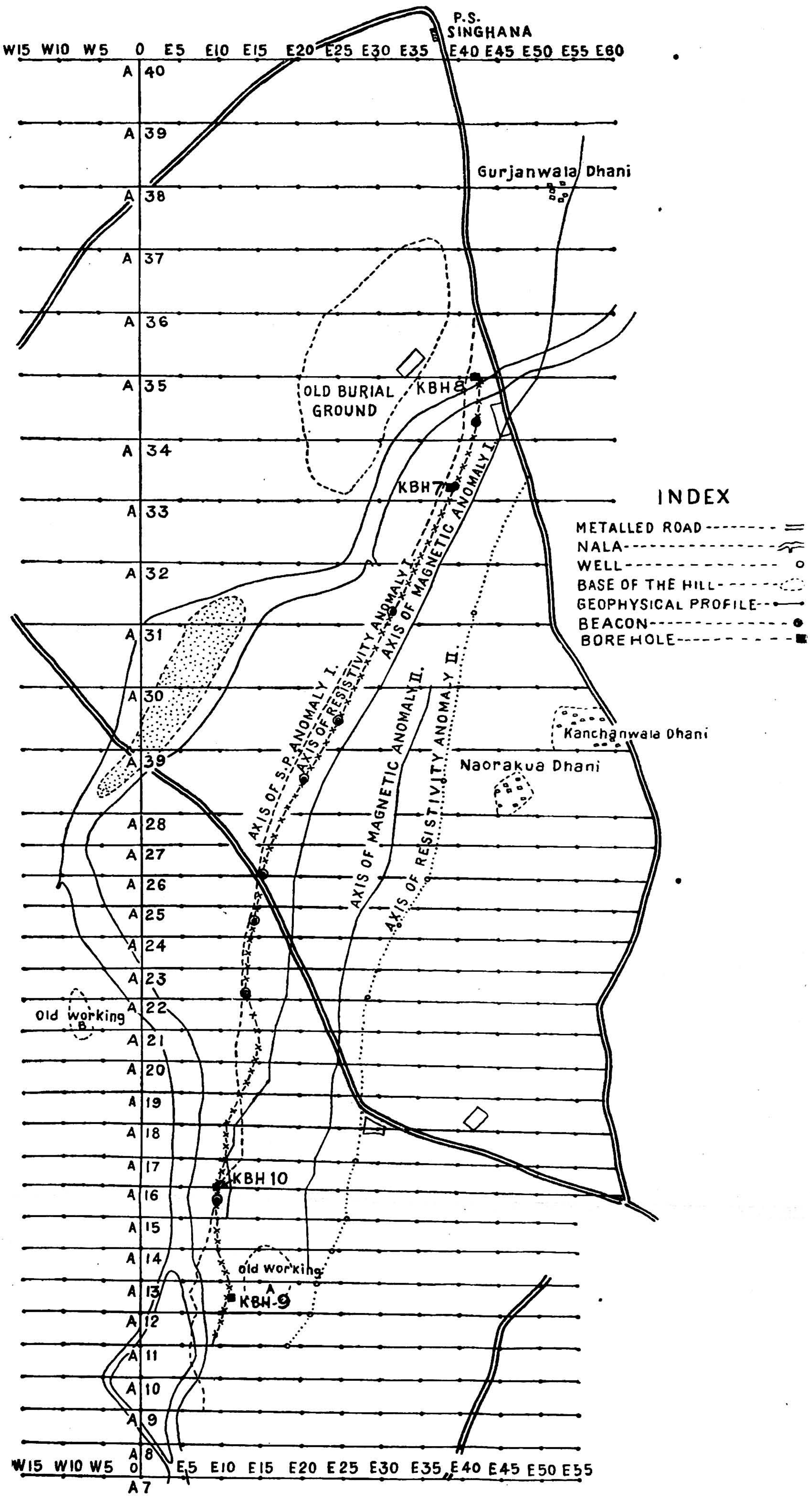
Conclusions : The results of the geophysical investigations for copper-ore carried out in the country bring out the scope of application of the various geophysical methods with their advantages and limitations to different areas under different geological conditions as discussed above. While the self-potential and resistivity methods would be quite useful and effective when economic sulphide ore deposits of copper occur in soft, foliated rocks under favourable ground water conditions, they invariably fail when the ore occurs as dissemination in fine-grained, compact and tight host rocks. In the latter case, the Induced Polarisation method is likely to prove to be substantially

PLATE 46

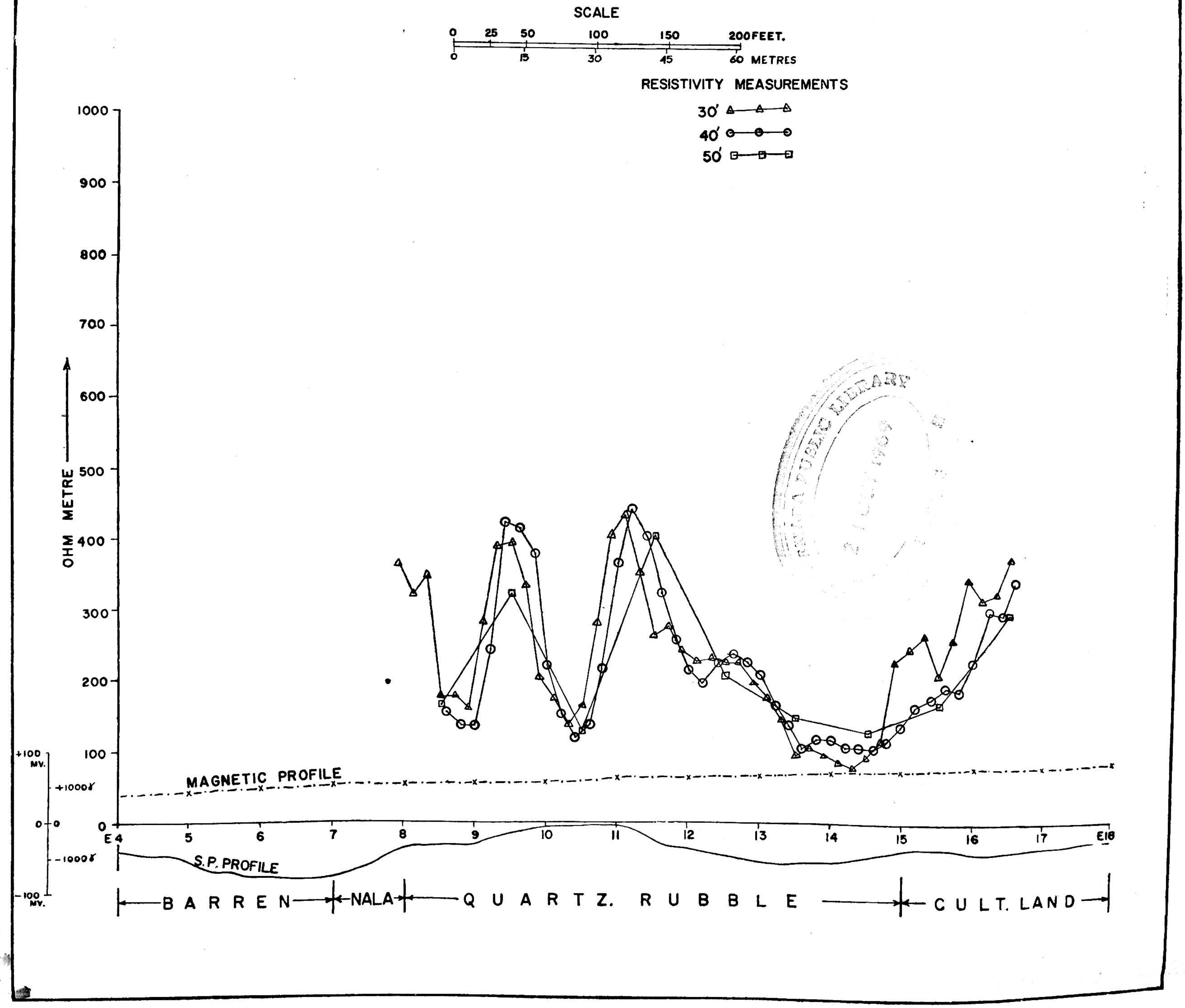
ELECTRICAL AND MAGNETIC SURVEY
SINGHANA-BANAWAS AREA, KHETRI COPPER BELT, RAJASTHAN

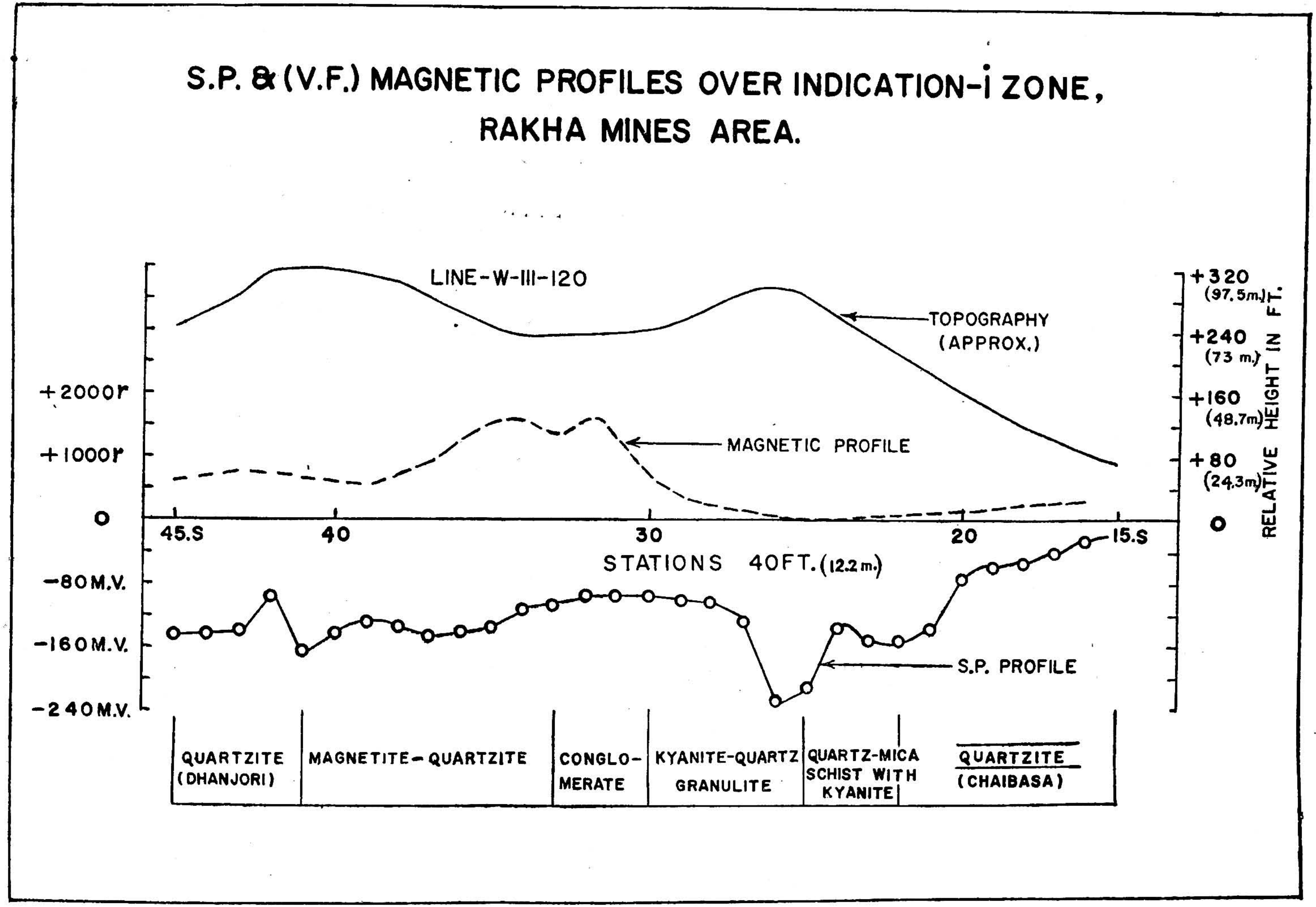
N

SCALE 0 61 122 183 244 305 366 METRE



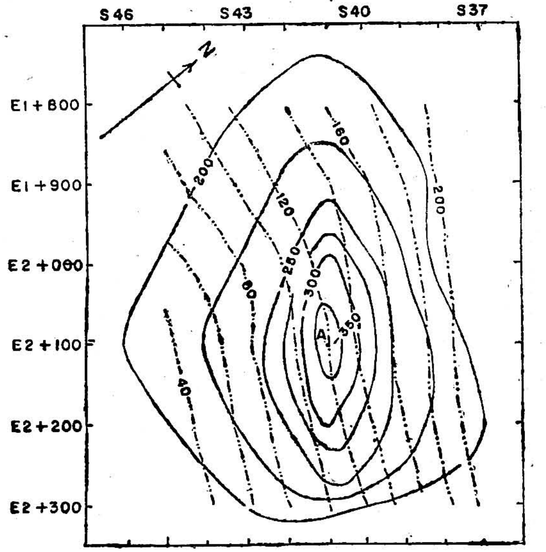
S.P., MAGNETIC AND RESISTIVITY PROFILES ACROSS INDICATION XI-E-A12, SINGHANA-BANAWAS AREA, KHETRI COPPER BELT, RAJASTHAN.




S.P. & (V.F.) MAGNETIC PROFILES OVER INDICATION-I ZONE, RAKHA MINES AREA.
LINE-W-III-120
TOPOGRAPHY (APPROX.)
MAGNETIC PROFILE
S.P. PROFILE
+2000γ
+1000γ
0
-80 M.V.
-160 M.V.
-240 M.V.
+320 (97.5m.)
+240 (73 m.)
+160 (48.7m)
+80 (24.3m)
0
RELATIVE HEIGHT IN FT.
45.S
40
30
20
15.S
STATIONS 40 FT. (12.2 m.)
QUARTZITE (DHANJORI)
MAGNETITE-QUARTZITE
CONGLO-MERATE
KYANITE-QUARTZ GRANULITE
QUARTZ-MICA SCHIST WITH KYANITE
QUARTZITE (CHAIBASA)

SELF-POTENTIAL CONTOURS AROUND TRAV. E2, RAKHA-SURDA AREA, SINGHBHUM DIST., BIHAR

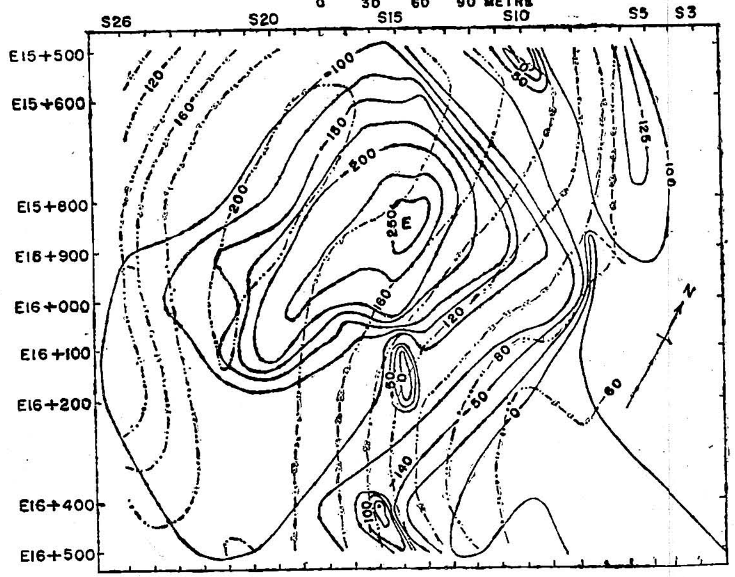
SCALE 100 50 0 100 FT.
0 30 60 METRE



S.P. CONTOURS (INTERVALS 25 MV.) ——200——
TOPOGRAPHY CONTOURS (INTERVAL 20FT.) -·-·-80-·-·
R.L. OF STN. S42/E2+000 = 100FT. (ASSUMED)
INDICATION ZONE — — — — A

SELF-POTENTIAL CONTOURS AROUND TRAV. E16, RAKHA-SURDA AREA, SINGHBHUM DIST., BIHAR

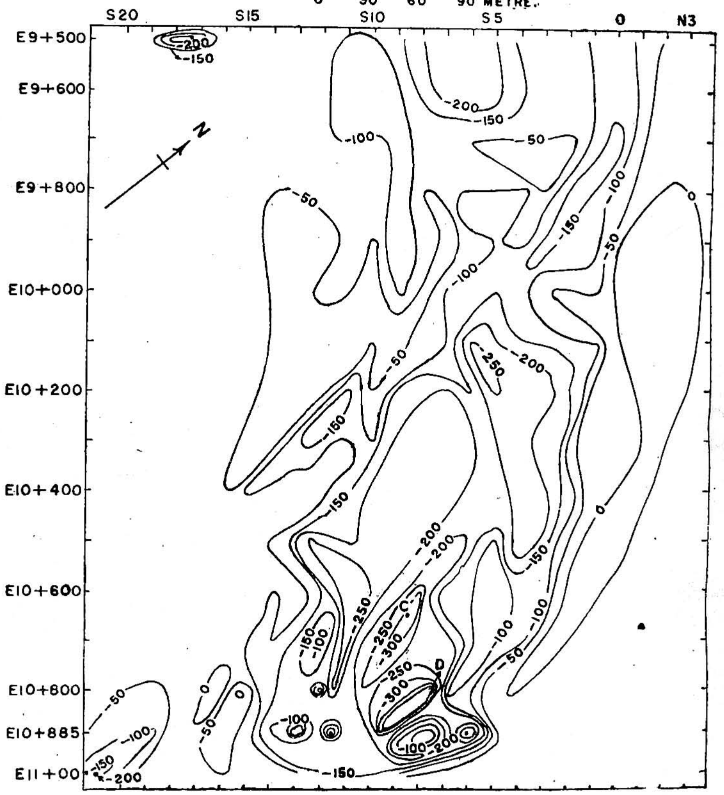
SCALE 100 0 100 200FT.
0 30 60 90 METRE



S.P. CONTOUR (INTERVAL 25MV.) ——100——
TOPOGRAPHY CONTOUR (INTERVALS 20FT.) -·-·-200-·-·-
R.L. OF S21/E16+500 = 200FT. (ASSUMED)
INDICATION ZONE —·— E

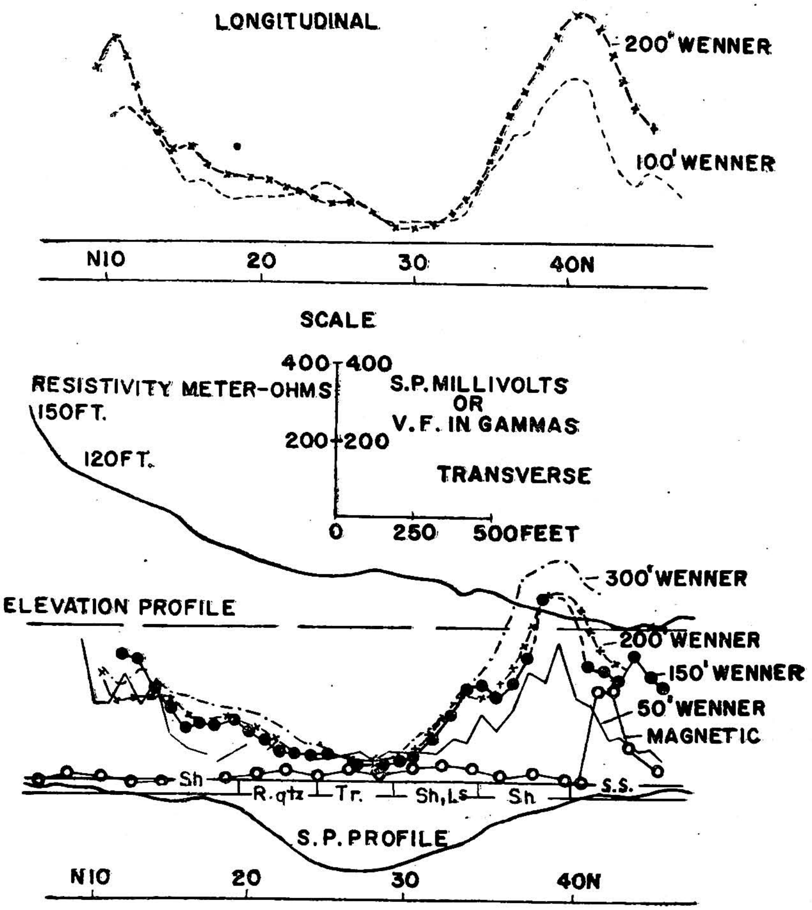
SELF-POTENTIAL CONTOURS AROUND TRAV. E10, RAKHA-SURDA AREA, SINGHBHUM DIST., BIHAR

SCALE 100 50 0 100 200FT.
0 30 60 90 METRE



S.P. CONTOUR INTERVAL 50MV.
INDICATION ZONE —— C, D.

PLATE 50

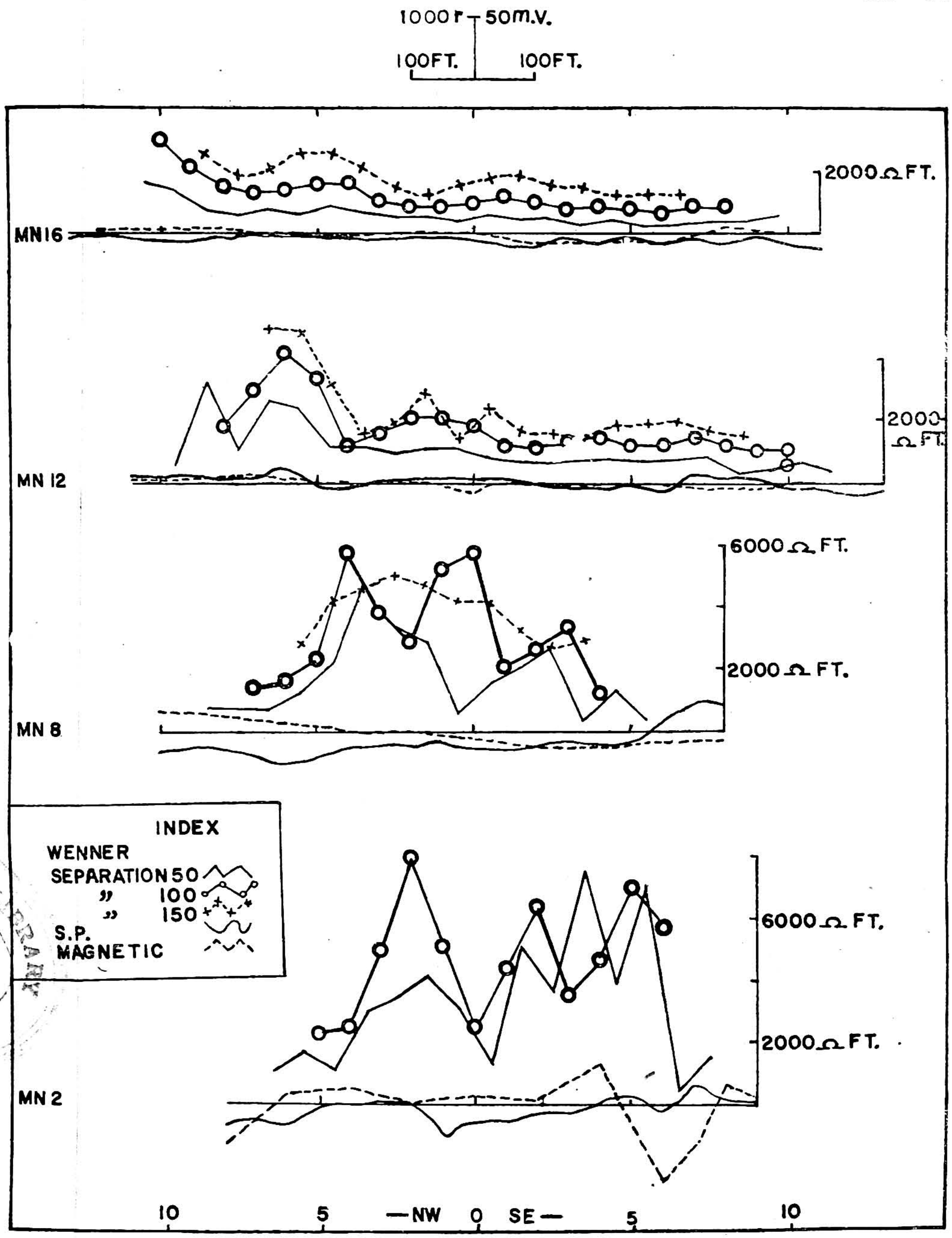


RESISTIVITY PROFILES ON INDICATION 12, WESTERN BLOCK, GANI AREA.

Sh (SHALE) R.qtz (ROLLED QUARTZ) Tr, (TRAPS) Sh, Ls (SHALE & LIMESTONE;) S.S. (SANDSTONE.)

SELF-POTENTIAL, RESISTIVITY AND MAGNETIC PROFILES GANI AREA, KURNOOL DISTRICT, ANDHRA PRADESH

PLATE 51



SELF-POTENTIAL, RESISTIVITY AND MAGNETIC PROFILES
MAMANDUR AREA, SOUTH ARCOT DISTRCT, MADRAS STATE.

OCT 1959

PLATE 52

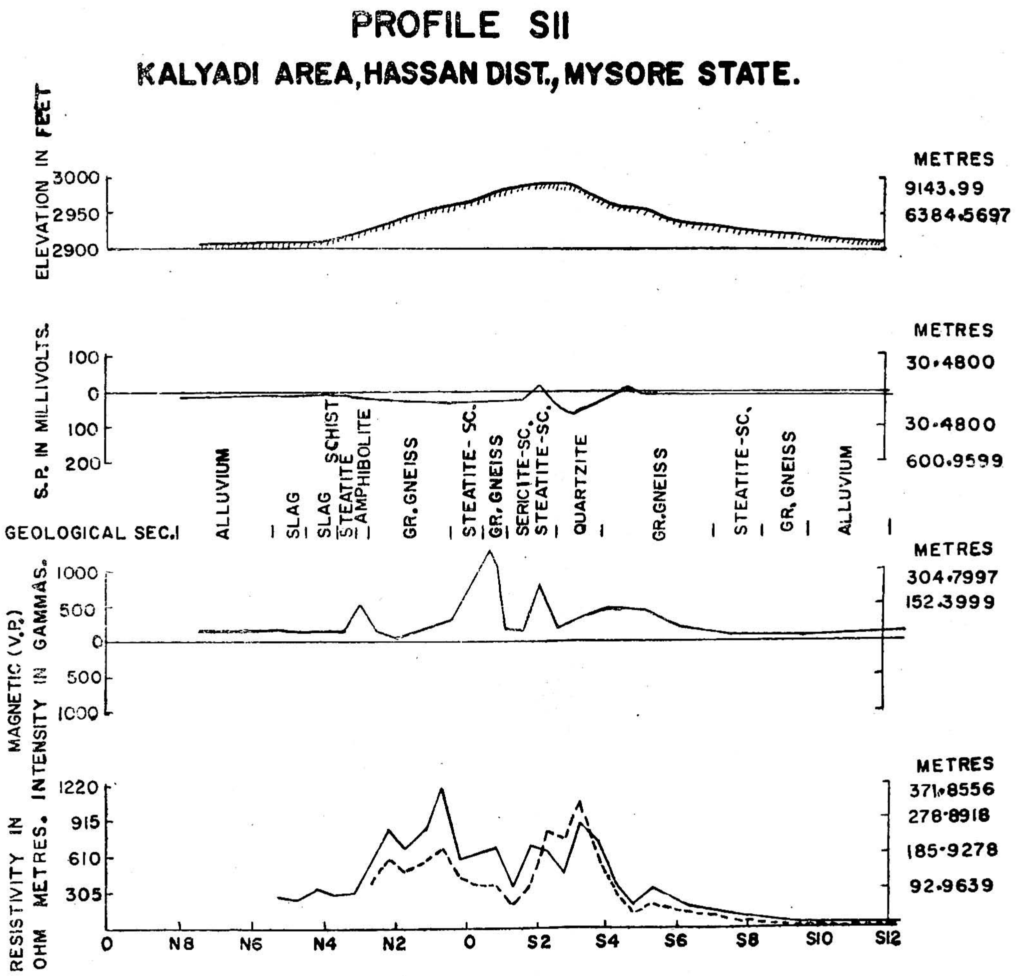
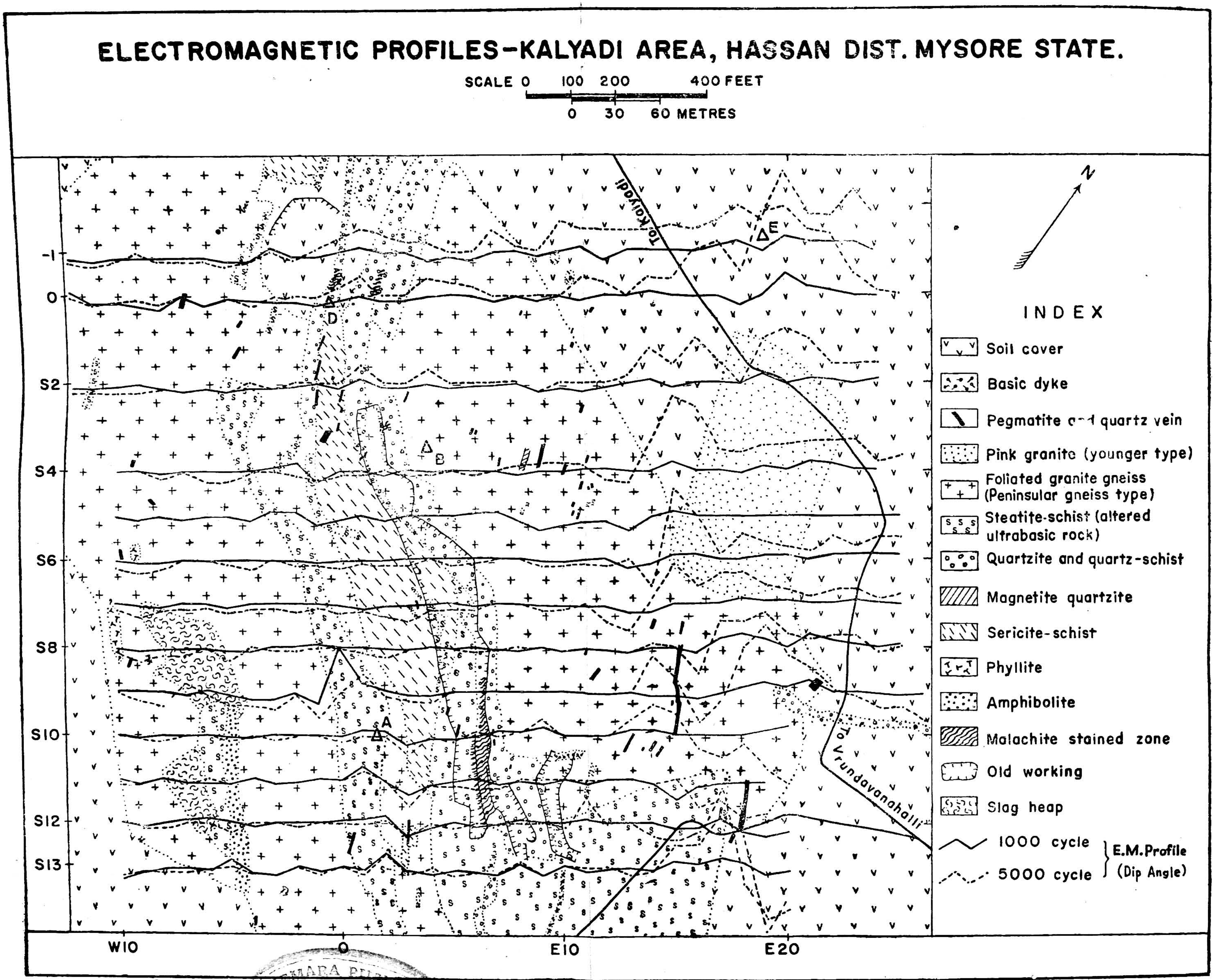

PROFILE SII
KALYADI AREA, HASSAN DIST., MYSORE STATE.
ELEVATION IN FEET
3000
2950
2900
METRES
9143.99
6384.5697
S.P. IN MILLIVOLTS
100
0
100
200
METRES
30.4800
30.4800
600.9599
GEOLOGICAL SEC.
ALLUVIUM
SLAG
SLAG
STEATITE SCHIST
AMPHIBOLITE
GR. GNEISS
STEATITE-SC.
GR. GNEISS
SERICITE-SC.
STEATITE-SC.
QUARTZITE
GR. GNEISS
STEATITE-SC.
GR. GNEISS
ALLUVIUM
MAGNETIC (V.P.) INTENSITY IN GAMMAS.
1000
500
0
500
1000
METRES
304.7997
152.3999
RESISTIVITY IN OHM METRES.
1220
915
610
305
METRES
371.8556
278.8918
185.9278
92.9639
0
N8
N6
N4
N2
0
S2
S4
S6
S8
S10
S12

PLATE 53



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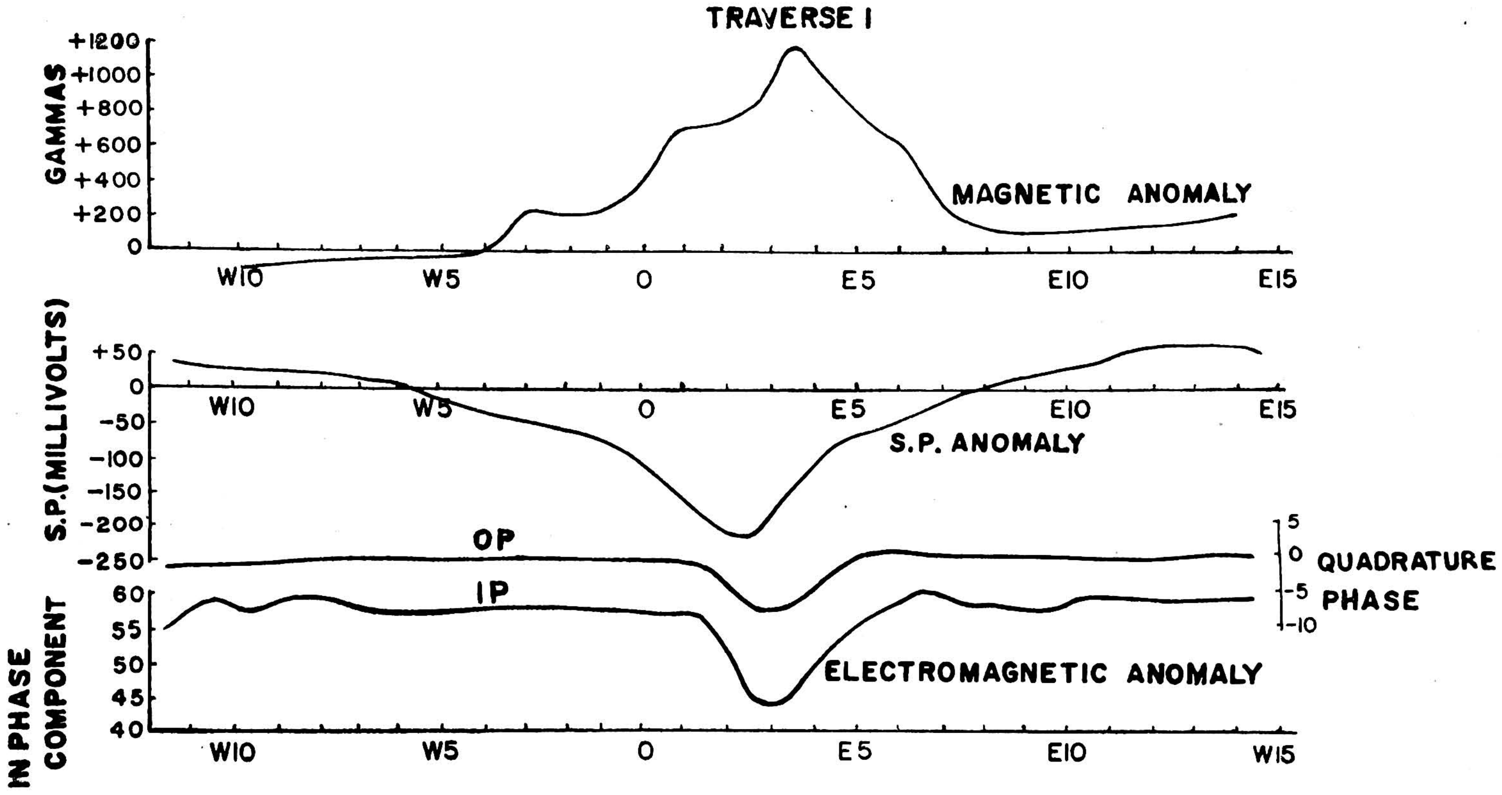
21 OCT 1969

ELECTROMAGNETIC, S.P. AND MAGNETIC PROFILES OVER TRAVERSE 1 IN THE AMBAJI AREA, BANASKANTHA DISTRICT, GUJARAT.



more useful and effective. This technique which is still in the development stage may be used increasingly in the future for the exploration for metallic ores, especially in disseminated form in view of the advantages already recounted. Drill hole techniques may be used increasingly in conjunction with exploratory drilling for the exploration of deep seated ore bodies. The airborne magnetic and electromagnetic methods will be useful for rapid coverage of inaccessible areas on a reconnaissance basis, but over highly disturbed terrain even these have limitations.

Future programme of work : Geophysical investigations for copper-ore are to be carried out on intensive and extensive scales by the Geological Survey of India in the coming years over the known copper belts as well as over new areas which may be brought to light as a result of further geological surveys. Geophysical surveys are to be extended over both the Singhbhum and Khetri copper belts to cover these areas systematically and to locate new ore bodies. Geophysical investigations for copper are also scheduled to be undertaken in the Mayurbhunj district of Orissa, in the Baramunda area of Bihar, the Sleemananad, Siddhi and Chaka areas of Madhya Pradesh, in the Kulu area of Himachal Pradesh and Narnaul area of Punjab, in Jammu and Kashmir State as well as in selected Himalayan areas where geophysical surveys may be practicable.

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AN APPLICATION OF THE POTENTIAL-DROP RATIO METHOD IN EXPLORING COPPER-ORES IN SINGHBHUM DISTRICT, BIHAR.

By

S. N. Saha

Geological Survey of India

(with Plates 55-57)

ABSTRACT

An electrical potential-drop ratio metnod was applied on the known copper deposits at Surda mines, Singhbhum, Bihar. The method was tried over a traverse across the strike of the copper lode with various separations and the results helped to indicate the lode eliminating the shallow geological features. This method has distinct advantage over the resistivity and self-potential methods, in locating large lodes, and screening all shallow geological disturbances.

INTRODUCTION

During the year 1960-61, a ratiometer instrument was used over the known copper deposits at Surda Mines of the Indian Copper Corporation. This instrument was used during 1949-50, for a reconnaissance survey at Pani mines, to locate galena-bearing quartz veins (Negi, 1949-50). No anomaly could then be found with the instrument. The aim of the present attempt was primarily to judge the efficiency and reliability of the method to locate known deposits and then to compare its results with those of the resistivity and Self-Potential (S. P.) observations in the the same area.

THEORY OF THE METHOD AND THE INSTRUMENT

An electric current is sent into the ground through one stake and the circuit is completed by connecting the other terminal of an A. C. generator (400 c. p. s.) with a stake put into the ground far away from the first one. At any point near the first stake, the equipotential lines

on the surface are concentric circles and the fall of potential with distance 'r' is approximately proportional to 1/r. This is true only when the observations are made in the vicinity of the first stake. Along the lines joining the two stakes and near the first stake, observations are made with three aluminium electrodes placed equidistant (a) from each other and driven into the ground (Pl. 56). The ratio of the potential drop of the first gap between the electrodes with the next gap is measured by an A. C. Potentiometer bridge unit, called ratiometer. A head phone is used to detect the null. Any difference of phase between the two gaps is also measured by the ratiometer by introducing a compensating variable condenser in parallel to any of the resistance bridge arms (Pl. 56). The ratio of the potential-drop is measured along stations at equal intervals, from near the first stake up to about 1/3 the distance to the far stake. The potential-drop ratio (P. D. R.) is then corrected for the normal ratio (r + a) / (r — a) by division and plotted. The near stake is then put in an identical position on the far side of the last station covered by the ratiometer, and the far stake put along the line towards the original first stake, but far beyond it. The same set of observations are then taken in this backward profile, corrected for the normal ratio, and plotted on the earlier forward profile. This is done as follows. For the forward profile, ratios less than one are plotted on the negative side of a base line (marked 1 in Pl. 56) graduated till zero. The ratios greater than one are converted into their reciprocals and plotted from one to zero on the positive side of the base line (Kihlstedt, 1934). The same method of plotting is adopted for the backward profile. The mean values of the backward and forward profiles at all points are then plotted. This profile (shown in thick line in Pl. 56) is the anomaly profile, which is free from the shallow geological anomalies as are quite apparent in the individual forward and backward P. D. R. profiles. The disturbance of the electrical fields due to shallow geological bodies will thus be eliminated by this process. When a conductor of appreciable depth extent is present, the forward and the backward P. D. R. profiles advance away from their respeetive near stakes, and thus, their average appears as a 'high' compared to the flat response at other places. It may be referred here, that in text books the plotting has been reversed taking into account the P. D. R. between the rear gap and the near gap, thus, giving rise to an apparent 'Low' over large conductive bodies.

If V_1 and V_2 be the potential-drops between the two equidistant pairofgaps, then (Heiland, 1940)

$$\frac{V_1}{V_2} = \frac{Z_1}{Z_2} = \frac{\sqrt{R_1^2 + X_1^2}}{\sqrt{R_2^2 + X_2^1}}$$

where R_1 and R_2 are the resistances of the arms of the ratiometer bridge and X_1 and X_2 the capacitive reactances, with $X^1 = \frac{1}{2\pi fc_1}$ and $X_2 = \frac{1}{2\pi fc_2}$. Equating the real and imaginary parts, the real component gives,

$$\frac{R_1}{R_2} = \frac{V_1 \text{ Cos } \tan^{-1} \frac{X_1}{R_1}}{V_2 \text{ Cos } \tan^{-1} \frac{X_2}{R_2}} \equiv \frac{V_1}{V_2}, \text{ when } X_1 \text{ and } X_2 = 0.$$

The imaginary component is given by,

$$\theta = \tan^{-1}\frac{X_1}{R_1} - \tan^{-1}\frac{X_2}{R_2}.$$

Under normal circumstances X_1 and X_2 are negligible and hence the resistance ratio of the ratiometer shows the real potential-drop ratio. Thus, the backward and forward profiles compensate each other in the absence of any capacitive reactance. Near a large conductor the capacitive reactance becomes prominent and thus, the value of R_1/R_2 does not give the actual V_1/V_2, but only the real part of it. Hence, they do not compensate each other in the backward and forward profiles with the ratiometer. The phase difference θ curve also shows a 'high' over the conductor.

The ratiometer used in this survey has been modified using condensers in parallel with the resistances. If R be the resistance and C be the capacitance of any arm in the ratiometer, then the admittance,

$$\frac{1}{Z} = \frac{1}{R} + \frac{1}{\frac{1}{j2\pi fC}} = \frac{1}{R} + j2\pi fC$$

If $\frac{1}{R}$ = k = Conductance, and $2\pi fC$ = l = Capacitive Susceptance, the admittance = k + jl. Therefore the ratio of the potential-drop is given by

$$\frac{V_2}{V_1}=\frac{K_1+jl_1}{K_2+jl_2}$$

The variable capacities and resistances are so graduated that the conductances k_1 and k_2 and susceptances l_1 and l_2 are in the same units. The unit of conductance is of a resistance of 300,000 Ohms. The Susceptance of the condenser of 0.001 micro farad at 535 c. p. s. approximately equals the above conductance.

The bridge has three dials. Two of them are for varying the resistance in one limb of the bridge. One of them for coarse and the other for the fine adjustments of the resistance. The third one varies the capacitance, which can be included in any of the two bridge arms.

The impedances of the two gaps on the ground form the third and the fourth arms of the bridge. The ratio of the impedances of these two gaps on the ground is directly evaluated by adjusting the resistances and the capacity of the variable condenser of the ratiometer with the help of the null amplifier and the headphone. The ratio can be read on the resistance dials of the ratiometer. The phase change is recorded in the phase dial.

GEOLOGY OF THE AREA AND THE LAYOUT OF THE SURVEY

The geology of the area has been dealt with in details by Dunn (1937 & 1942). The occurrence of copper in Singhbhum is generally connected with the intrusion of soda granite presumed to have taken place in and around the vast zone of overthrust, where metamorphosed rocks of the north were thrust bodily against the less altered ones to the south. The thrust zone appears to have taken a turn towards south-east near the Surda mines. (Pl. 55).

The area may be divided broadly into three zones. (1) Zone to the north of the thrust zone. (2) Thrust zone, (3) Zone to the south of the thrust zone.

Zone (1) : It consists mostly of mica-schist. A well defined bed of quartz-granulite varying to quartz-schist is interbedded within the

mica-schist. This quartz-granulite commonly forms low ridge above the mica-schist. It can be followed quite consistently over a distance of several miles, but to the west it becomes impersistent and is obscured by the surface cover. Fine magnetite and also ilmenite invariably occur in the rock.

Zone (2) : Along the thrust zone, the Chaibasa stage of rocks has been thrust over rocks of the Iron-ore stage, Dhanjori quartzite-conglomerate and lavas. A characteristic of the shear zone is the introduction of chlorite into the schist, so that the original phyllites, quartz-schists, lavas and granite-schists have all been altered to chloritic-schists.

Zone (3) : To the south of the shear zone, the iron-ore stage consists of phyllites, with tuffs, banded quartzite, including banded hematite quartzites and basic igneous rocks.

The ratiometer traverse was laid across the thrust zone in the general direction E. N. E.—W. S. W. (Pl. 55) covering a total distance of about 800 m. (½ mile). Stations were laid at intervals of 15 m. (50 ft.) along the traverse (across the Surda mines) crossing the mica-schists, shear zone, and the rocks to the S. S. W. The actual exposed portion of the old copper working was near station 16 W and almost on the top of the hill (S. S. W. slope) into which Surda mines are being developed. It has been reported that 2·5 m. (8 ft.) thick quartzite band along the shear zone dipping about 45° to the N. N. E. has been mineralised all along in depth, within the mines. The minerals are mostly pyrite, chalcopyrite, and some pyrrhotite. That the lode is continuous even at great depths, has been proved by the reported finding of the drill-holes put on the north east side of the shear zone (near stn. 30° E. approximately).

At a depth of about 240 m. (800 ft.) (normal to the dip direction) copper lode was struck, up to a width of about 2.4 m. (8 ft.).

Field Procedure

An Alternating current generator running at 400 c. p. s. was used to drive into the ground a current of the order of 400 to 500 mA at 115 volts. The near ground stake was made by driving five copper electrodes into the ground in the shape of a pentagon and amply watering them. The far stake was put similarly, about 2.5 km. (1½ miles) from the near one along the extended direction of the traverse. The observation with the ratiometer was started from a

station such that the near station was appreciably away from the near stake. This was, to avoid the high gradient of the potential-drop in the close vicinity of the stake. At first, the observations were taken with the ratiometer electrode interval of 15.24 m. (50 ft.). Similarly, stations were repeated for electrode intervals of 30.5 m. (100 ft.) and 61 m. (200 ft.). Thus, the forward profiles for various separations were observed and then plotted. Keeping the near stake now in an identical position but beyond the last station observed in the forward profile, and the far stake at approximately 2.5 km. (1½ miles) in the opposite direction, the backward profiles of the P. D. R. for the above separations were observed. The forward and the backward profiles were then plotted in the usual way after making the normal ratio correction. The difference of the phase angles were recorded in terms of 'tan θ'. This difference was also plotted on the profile for all the stations. Since 400 c.p.s. was used, the actual value of the tan θ can be converted from the one given in the dial (calibrated for 535 c.p.s.) However, the exact value of tan θ is not important, and hence value were plotted in arbitrary units. The results of the plot are shown in Plate 56.

Discussion

The P. D. R. plot shows a clear response over the lode near station 16 W. This indication becomes more pronounced with the increased separation between the prospecting electrodes. The 'high' which is indicative of the conductive zone, can be seen in the 15.0 m. separation curve. This 'high' is followed faithfully at 17 W and I8 W respectively of the 30 0 m. and 60 m. separation curves. It can be easily seen, that the individual forward and backward traverses are too oscillating to give rise to any indication, definitely. The kinks, at 6 E and 4 W, in the 15 m. separation curve, at 1 E, in the 30 m. separation curve and at 2 E, on the 60 m. separation curve, are due to contact resistance which changes from the forward to the backward profile. These kinks could be avoided if observations were taken for the forward and backward profiles, with one set up of the prospecting ratiometer electrodes. This could be achieved throug suitable communication arrangement and elaborate cable laying. In the present set up, no facilities of the above type were available and the forward and

PLATE 55

GEOLOGY NEAR SURDA MINES,
SINGHBHUM, BIHAR

SCALE 1 0 1 2 MILES

0 1 2 3 4 Km.

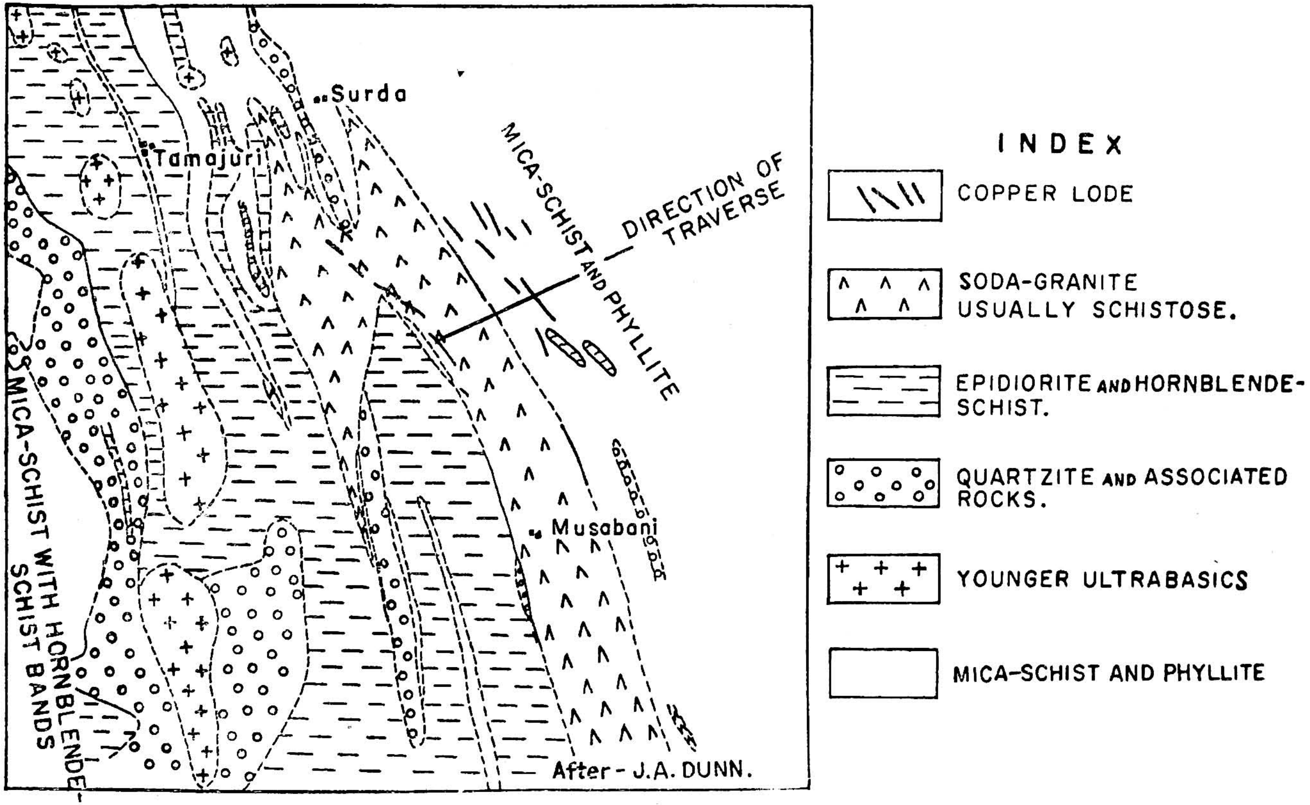

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PLATE 56

POTENTIAL- DROP RATIO PROFILES ACROSS SURDA COPPER MINES, SINGHBHUM, BIHAR

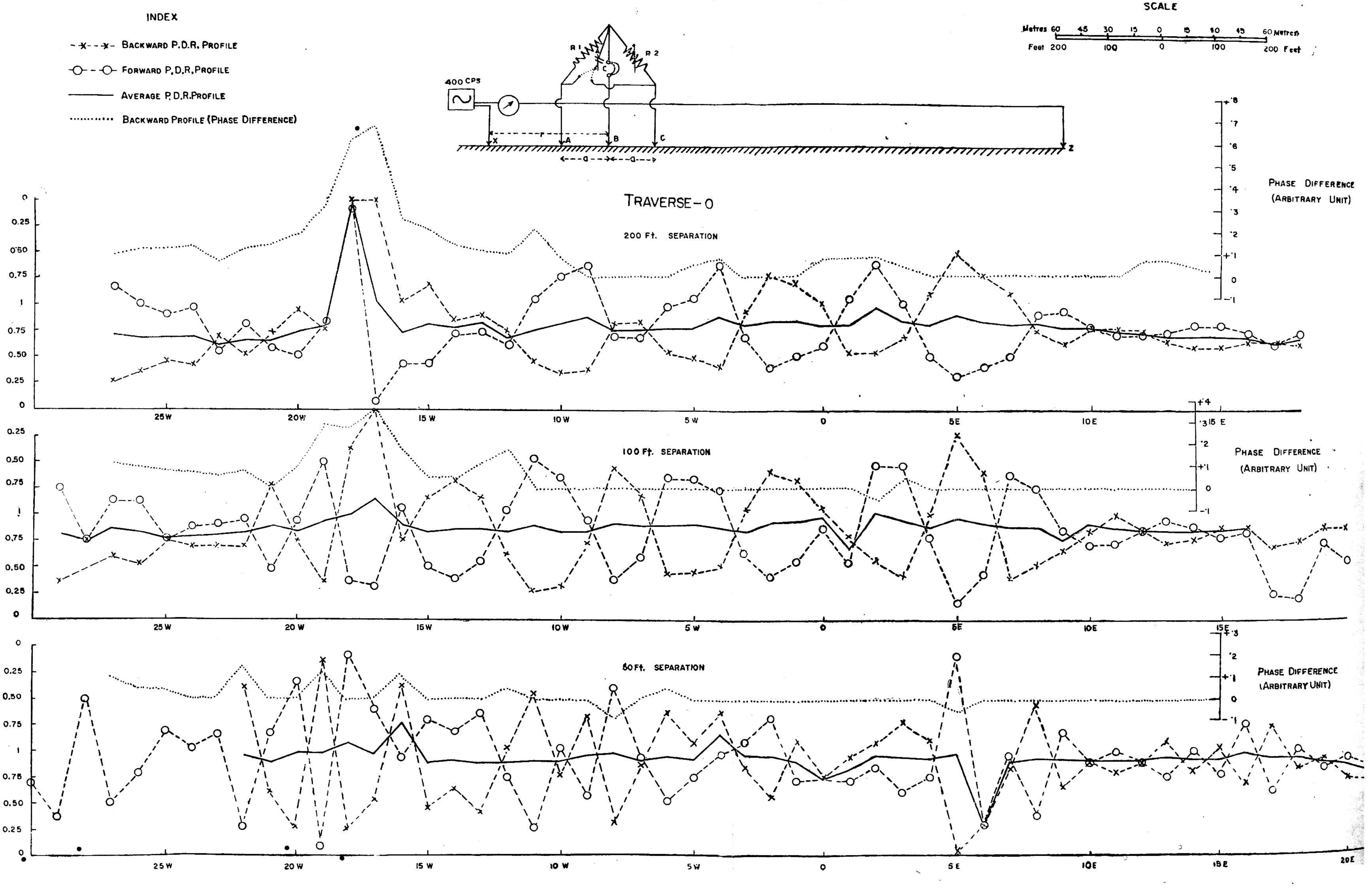
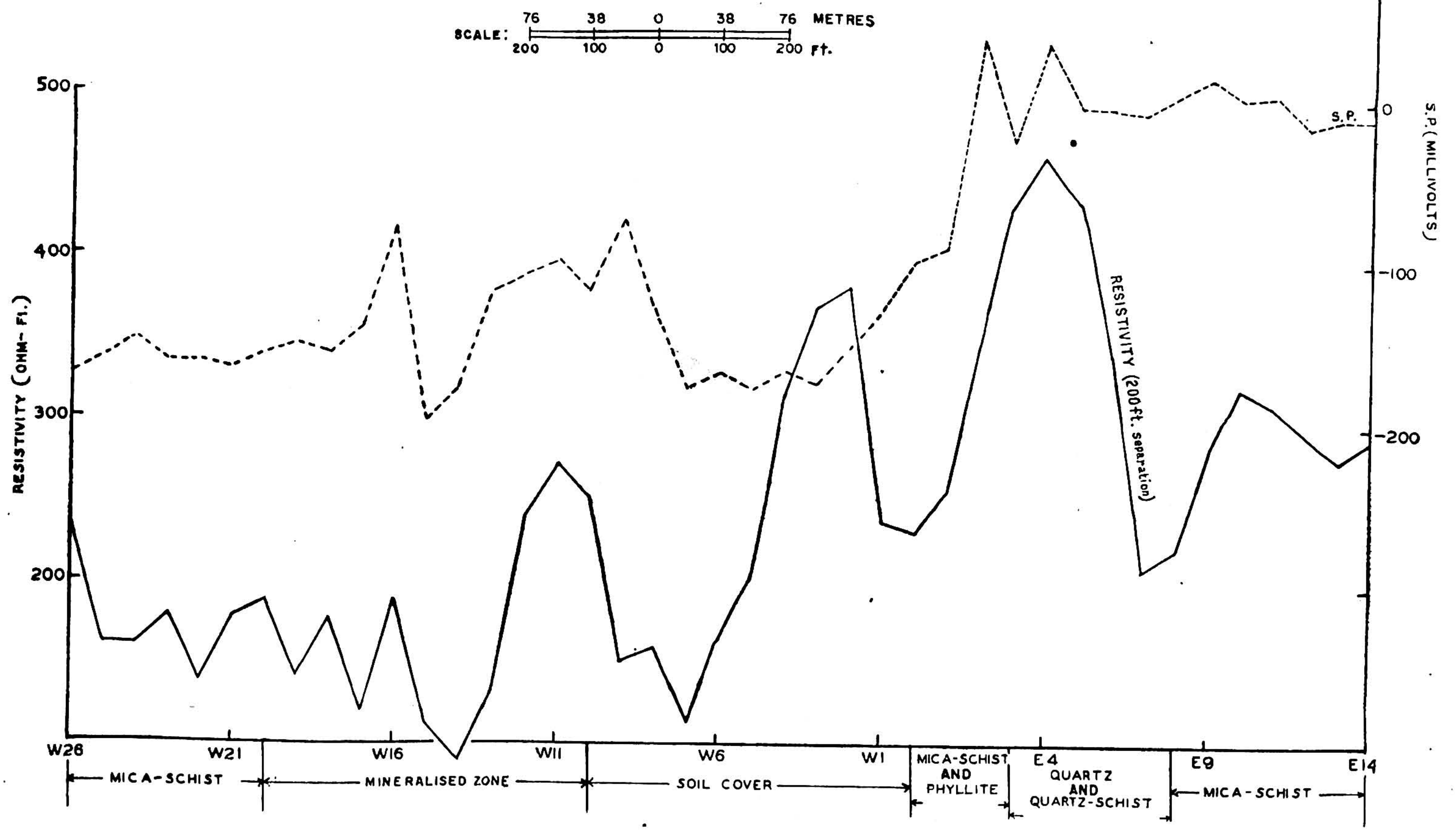


PLATE 57

S.P. AND RESISTIVITY PROFILES ACROSS TRAVERSE-O, SURDA MINES, SINGHBHUM, BIHAR.



the backward profiles were observed on separate days. In the present case however, most of the kinks have been eliminated in the average P. D. R. profile of large separations. The persistent 'high' in the region 16 W to 18 W, however, remained the same in all the separations. This indicates the possibility of the presence of the conducting ore body, presumably the copper lode, at depth in that region.

The difference of phase between the two gaps of the prospecting electrodes at any station, have been plotted in terms of tan 0 (arbitrarily, since a different frequency is used) as dotted lines. This curve was only plotted for the backward profile. This also indicates a 'high' in the region 15 W to 18 W in all the separations. This is indicative of the conducting zone and may be taken as an auxilliary indication of conductive bodies. The other phase indications are either not pronounced or not persistent.

A glance at Plate 57, in which the S. P. and the resistivity profiles are plotted over the same stations, indicates not a very good picture of the anomaly. The resistivity is highly undulating showing several lows and highs. Even though the pronounced low at W 14 indicates the approximate position of the lode, it is difficult to interpret the other lows. The S. P. profile shows a drop to a low value at 0 and is continued throughout, towards west. The prominent lows, between W 3 and W 7 and at W 15 are present. Even though the low at W 15 appears to be a sharp one and probably indicates the ore body, the broad low from W 3 to W 7 cannot very well be explained. The fluctuating resistivity values and the broad S. P. low cannot pinpoint the exact location of the copper lode. On the other hand, the P. D. R. traverses, particularly that with 200 feet electrode separation shows a clear indication over the ore body.

CONCLUSIONS

Considering the results obtained by the three methods, P. D. R., S. P., and the resistivity over the known mineralised area, it is evident, that the P. D. R. methods has been more helpful in indicating outline of the copper lode than other methods. It may be expected that in spite of its cable laying difficulties and other elaborate arrangements this method may under favourable conditions give even better results than the other methods.

Acknowledgements

The author is indebted to Shri L. N. Kailasam, Chief Geophysicist, for his encouragement, and to Shri D. Gupta Sarma for making the instrument fieldworthy. He gratefully acknowledges the help rendered by the Indian Copper Corporation to facilitate the investigation and also to Shri I. V. P. Sastry, Geophysicist, G. S. I. for helping him to complete the survey.

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GEOPHYSICAL EXPLORATION FOR COPPER—ORES IN DARIBA, KHOH AND ADJOINING AREAS, ALWAR DISTRICT, RAJASTHAN.

By

P. M. Mathew

Geological Survey of India

(With Plates 58-61)

ABSTRACT

A geophysical survey for copper-ore employing self-potential and magnetic methods, was carried out in Dariba, Khoh and adjoining areas in Alwar district, Rajasthan during 1953—54. The results obtained indicated significant self-potential anomalies in four areas (1) Dariba Mine area (2) the Dariba Nala area (3) Khoh-Dariba area and (4) the area about half a mile S. S. W. of △ 1911. Exploratory drilling carried out by the Department of Atomic Energy and the Indian Bureau of Mines met with Copper lodes in two of these areas *viz.* the Dariba mine and the Dariba *nala*. Drilling carried out so far in the Khoh-Dariba zone has not met with any significant copper lodes.

INTRODUCTION

The old copper mine at Dariba, Alwar district, Rajasthan, has been well known for a long time. There are indications that the ancients had worked these deposits for over a number of years. The working originally consisted of small pits on the Dariba hill side.

In an article in Major Powlett's Gazetteer Ulwar, Major Cadell (1873) described the preparation and reduction of copper-ore at Dariba mines. T. F. Andreson gave a description of the copper mine and smelting operations in the Mining Journal of 1884. C. A. Hacket of the Geological Survey of India visited the area in 1870, when the mining had almost ceased.

A. M. Heron (1917) examined the old mine and described the geology of the area. G. S. Kapur and Co. who took over the lease of the mine in 1940 did little exploratory work, except clearing some debris in the old levels and dewatering the mine.

About 400 m. south-west of the old Dariba mine along side the Dariba *nala*, some old shafts as well as heaps of debris are noticed. Crookshank recommended prospecting this area along with exploratory work in the Dariba mine.

About 2.8 km. N. N. W. of Baldeogarh and about 800 m. S. S. W. of △ 1911, there are some old pits in a band of phyllites Malachite stains are occasionally noticed in the dumps near the pits.

A geophysical survey for copper-ore in the Dariba, Khoh and adjoining areas was conducted from November 1953 to June 1954, by the Geological Survey of India.

In December 1953, B. Srikantan carried out detailed underground mapping of the Dariba mine along with detailed surface geological mapping and geochemical survey of the area. Subsequently exploratory drilling was carried out in the Dariba mine area by the Atomic Energy Commission. Later the Indian Bureau of Mines took up systematic exploratory mining and drilling in Dariba and adjoining areas.

Location

The area geophysically surveyed forms part of the Rajgarh *tehsil*, Alwar district, Rajasthan (Pl. 58). The most prominent village in the area *viz.* Khoh (27°11′ : 76°23′ ; 54 A/SW) is connected by road to Rajgarh town about 35 km. due E.N.E. and to Alwar town about 72 km. to the N.N.E. Dariba (27°01′ : 76°24′) is an abandoned village about 2·5 km. south-east of Khoh.

Topography

The main topographical features of the area consist of the Khoh-Dariba-Budhpura hill range, flanked on either side by two flat valleys, the Khoh-Dariba valley and the Baldeogarh valley. The drainage of the area is mainly towards south.

GEOLOGICAL FEATURES

This part of Rajasthan was first geologically surveyed by C. A. Hacket in 1870. Subsequently it was resurveyed by A. M. Heron

between 1908 and 1911. B. Srikantan carried out detailed underground mapping of the Dariba mine and detailed surface geological mapping of the area during field seasons 1953-54. He classified the constituent rock formations as follows :—

Recent	Alluvium, River gravels and soil
Alwar Series	Quartzite Grits and Conglomerate Phyllite
——Unconformity——	
Raialos	Marble with quartzite intercalations and associated Amphibolite (metadolerite).
——Unconformity ?——	
Pre-Delhis	Porphyroblastic gneiss and biotite-schist.

The valley south of Baldeogarh (27°08′ : 76°23′) is formed by porphyroblastic gneiss. Thick alluvium covers the contact between marble and this gneiss. The porphyroblastic gneiss is also noticed on the north-eastern and eastern flanks of the hill range from Khoh to Ghatrah. (27°08′ : 76°24′).

The Khoh-Dariba valley and the northern part of Baldeogarh valley are formed mainly of marbles with a number of quartzite and siliceous bands. Calc-silicate bands are also abundant in the vicinity of quartzites. The amphibolite (metadolerite) is noticed mainly on the south-western flank of the Khoh-Dariba range. It is also seen along some fault zones in the area.

Phyllites occur in the north-eastern flanks of the Khoh-Dariba hill, in the eastern flank of the hill near Dariba and in the area about four kilometres S.S.W. of △ 1911. They are generally covered by rubble and talus. Strike faults are generally noticed at their contacts with other rock formations. Indications of copper mineralisation are mostly found in phyllites.

The summits and the upper flanks of the Khoh-Dariba-Budhpura range are formed of grits and quartzites. On the Dariba hill, two

main zones of conglomerates have been noticed in the grits. The dips of this grit and the quartzite group of rocks are steep. The alluvium in the Khoh-Dariba and Baldeogarh valleys has a maximum thickness of about 13 metres. Irregular gravel beds are also noticed within the alluvium.

According to B. Srikantan (Roy, 1961, p. 90), the main structural feature of the area is the 'Baldeogarh anticline' plunging at a low angle to the north with a number of steeply dipping faults traversing parallel to the axial plane of the fold. The strike faults are found to traverse all the formations in the area. A few of the fault zones are mineralised. Several cross faults are also noticed in this area but their displacements are of minor nature.

In the Dariba Copper mine, the mineralisation is practically confined to the phyllites which are bounded on either side by faults along the contacts with quartzite and grit. At places of more intense metamorphism, the phyllites are metamorphosed to biotite-schists, with large rounded grains of felspar. Most of the stopes are located in altered phyllites. The faults have varying dips, generally westwards.

The chief sulphide minerals are chalcopyrite and pyrrhotite, with minor amounts of iron pyrite and associated copper sulphides. Secondary sulphates and carbonates are also present. The mineralisation is of the nature of crack, fissure, joints and bedding fillings within the fault zone and occurs in the form of stringers, thin veins and irregular patches and disseminations.

GEOPHYSICAL SURVEY

Self-potential or spontaneous polarisation and magnetic methods were employed for the geophysical survey.

A direct current potentiometer constructed in the Geophysical workshop of the Geological Survey of India was used for self-potential measurements. Non-polarisable electrodes were of the copper/copper sulphate type and their performance was generally satisfactory. Magnetic (vertical force) measurements were made with a Watts vertical force magnetometer having a magnetic system of 30 gammas sensitivity.

The Geophysical survey, first commenced in the Dariba mine area, was later extended to the Dariba *nala* area, the Dariba-Budhpura area, the Dariba-Khoh area and the old pits area 800 m. S. S. W. of △ 1911. Reconnaissance traverse lines were laid about 60 m. (200 ft.) apart with measuring stations about 15 m. (50 ft.) intervals in the Dariba mine and the Dariba and *nala* areas and in area S. S. W. of △ 1911. Elsewhere the reconnaissance traverse lines were generally laid at 120 or 150 m. (400 or 500 ft.) intervals with stations at 15 m. (50 ft.) intervals.

For self-potential surveys, a base station was selected, about 180 m. (600 ft.) south of the present Dariba temple on a small mound. S. P. measurements were taken at each station along the traverse lines and these measurements were all tied to the base station.

Magnetic measurements were generally taken at alternate stations along the traverse lines, except in areas where high anomalies were observed; in such areas measurements were taken at every station. Magnetic measurements were all tied to a magnetic base station selected about 30 m. (100 ft.) west of the village well on the south-eatsern side of Khoh.

In areas where significant geophysical anomalies were indicated by the reconnaissance profiles, measurements were carried out along closely laid out networks of stations, for delineating the anomaly zones.

Results of the Geophysical Survey

Self-potential measurements : The reconnaissance traverse lines DN 8 to DS 100 extending from Dariba to Budhpura covered the Dariba mine and the Dariba *nala* areas. Self-potential profiles along these traverses indicated prominent negative self-potential anomalies in the Dariba mine and Dariba *nala* areas. These negative anomaly zones were delineated by measurements along closely laid out grid of stations.

The S.P. equipotential plan of the Dariba mine anomally zone is illustrated in Plate 59. The maximum negative anomaly observed in this zone on the surface, of minus 135 millivolts occured at station 24 W on line DS 9, close to the entrance to the incline of the old mine. Examination of the S.P. equipotential plan shows that the S.P. anomally

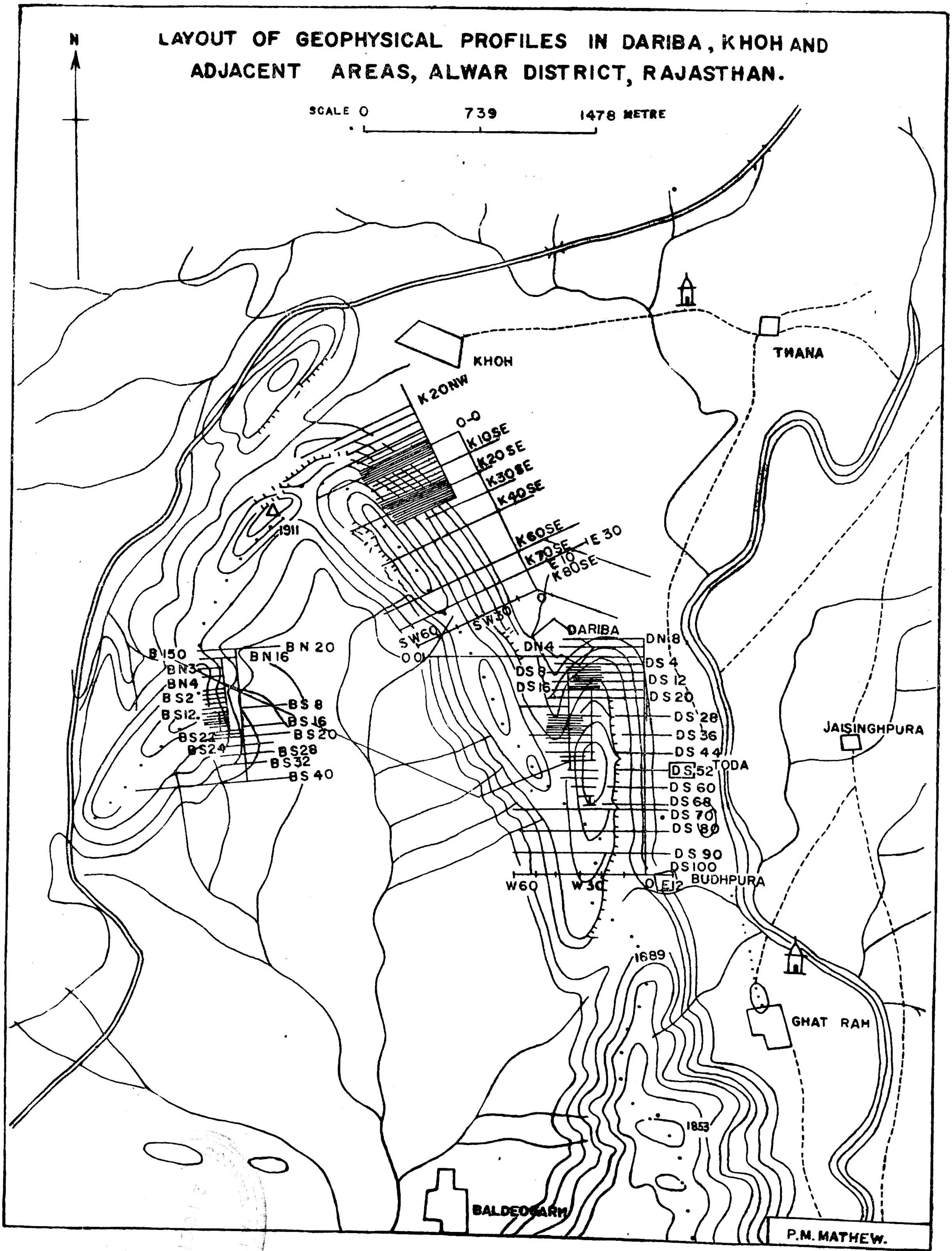
contours are rather elongated in the N.N.W.—S.S.E. direction, corresponding more or less generally to the strike of the rock formations here. It is also seen that the self-potential contours tend to broaden on the N.N.W. side of the anomally zone.

Self-potential measurements were also carried out inside the old Dariba mine along the old adit level, with stations at 15 m. (about 50 ft.) intervals. These measurements indicated negative self-potential anomalies ranging from minus 200 to minus 700 millivolts, from about station 7 about 90 m. (300 ft.) from the adit mouth to the end of the lower level. The maximum anomally of minus 700 millivolts was observed at station 15.

The other conspicuous anomaly zone indicated by the self-potential profiles between Dariba and Budhpura was the Dariba *nala* anomaly zone. The S.P. equipotential plan of this anomaly zone is illustrated in Plate 60. This plan shows that the self-potential contours are also generally elongated in the N.N.W.—S.S.E, direction, more or less parallel to the strike of the rock formations here. The maximum self-potential anomaly of about minus 115 millivolts observed in this zone occurred at station 39 W on line DS 30. Geologically, the anomaly zone occurs over a band of phyllites bounded on all sides by faults. As has been mentioned earlier, a number of old shafts are noticed in this area, but it was interesting to note that none of these fell within the area covered by the maximum self-potential anomaly contour of minus 110 millivolts in this zone.

The reconnaissance traverse lines K 20 N.W. to K 80 S.E. covered the Khoh-Dariba hill range extending from the south-eastern side of Khoh village to Dariba. The self-potential profiles along the reconnaissance traverse lines indicated an elongated negative anomaly zone extending over a length of about 600 m. (2000 ft.).

The S.P. equipotential plan of this Khoh-Dariba anomaly zone is illustrated in Plate 61. A general elongation of the self-potential contours parallel to the strike of the rock formations, is noticed here also. The equipotential plan indicates a few separate negative centres in this zone, the more important ones being near about stations 25 SW on K 22 SE line, 25 SW on K 16 SE line, 30 SW on K 4 NW line and 31 SW on line K 8 NW with magnitudes ranging from minus 130


LAYOUT OF GEOPHYSICAL PROFILES IN DARIBA, KHOH AND ADJACENT AREAS, ALWAR DISTRICT, RAJASTHAN.
N
SCALE 0 739 1478 METRE
KHOH
THANA
JAISINGHPURA
DARIBA
TODA
BUDHPURA
GHAT RAH
BALDEOGARH
1911
1689
1853
K20NW
0-0
K10SE
K20SE
K30SE
K40SE
K60SE
K70SE
E10
E 30
K80SE
SW30
SW60
O O
DN4
DN8
DS 4
DS 8
DS 12
DS 16
DS 20
DS 28
DS 36
DS 44
DS 52
DS 60
DS 68
DS 70
DS 80
DS 90
DS100
O EJ2
W60
W30
B 150
BN3
BN4
BN16
BN 20
BS2
BS8
BS12
BS16
BS20
BS22
BS24
BS28
BS32
BS40
P.M. MATHEW.

S.P.E.P. PLAN
DARIBA MINE ANOMALY ZONE

CONTOUR INTERVAL 10mv

SCALE 0 60 120 METRE

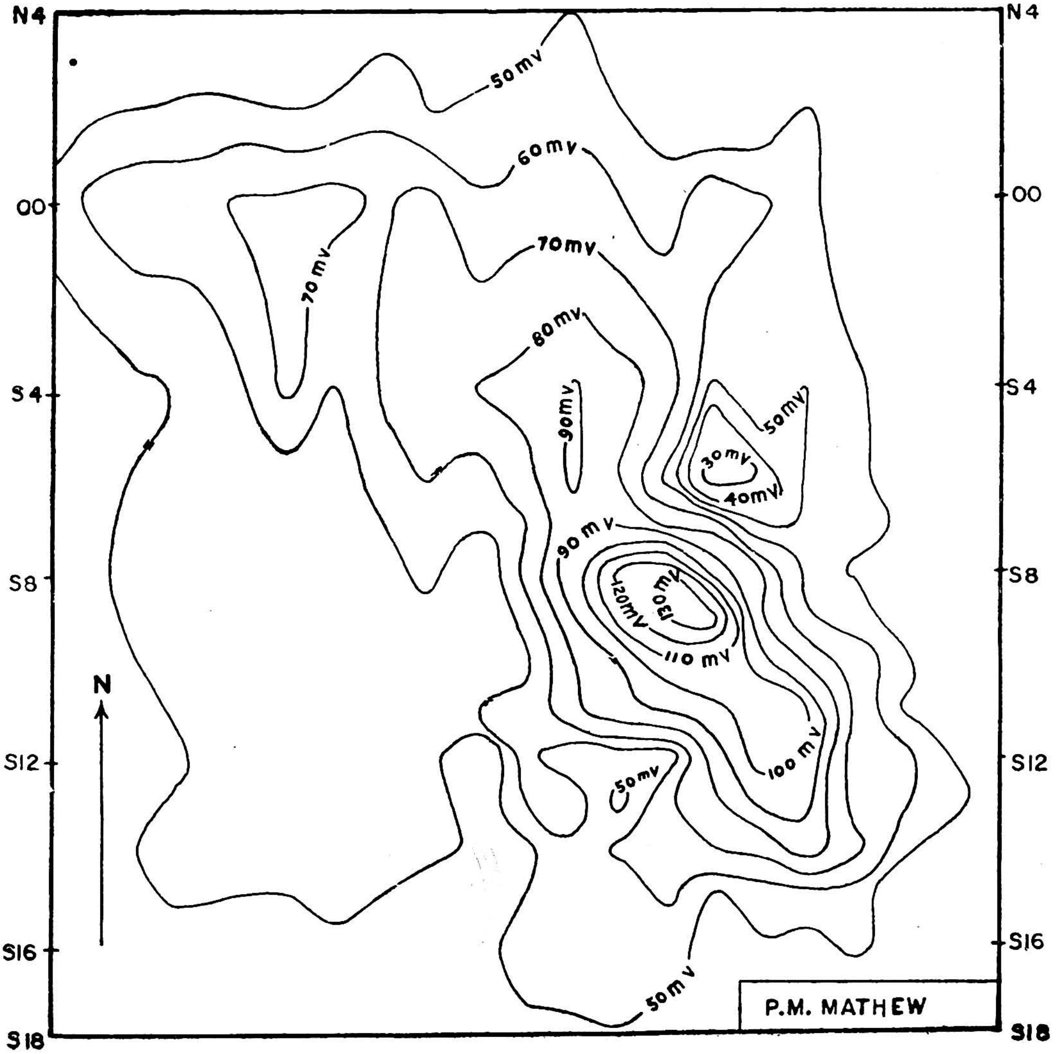


PLATE 60

S.P.E.P. PLAN
DARIBA NALA ANOMALY ZONE

CONTOUR INTERVAL 10 mv

Scale 0 60 120 Metre

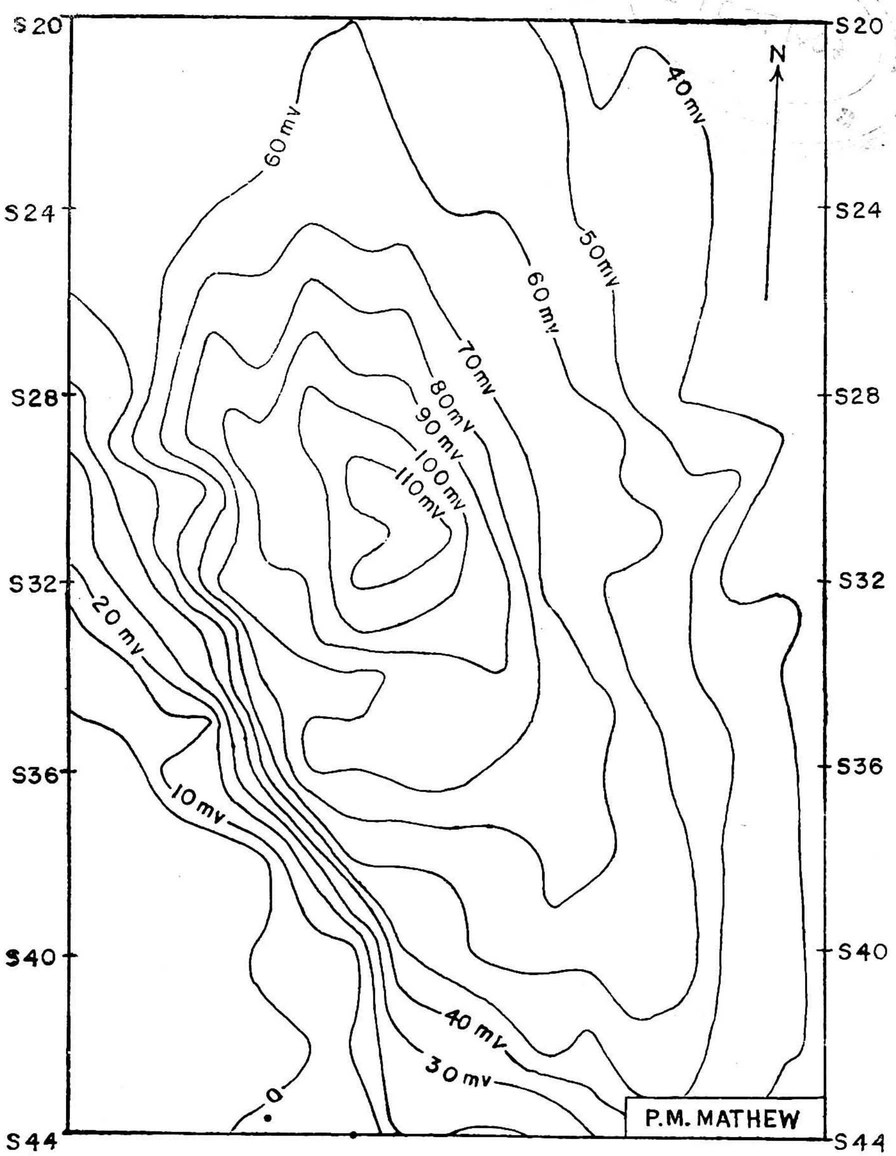
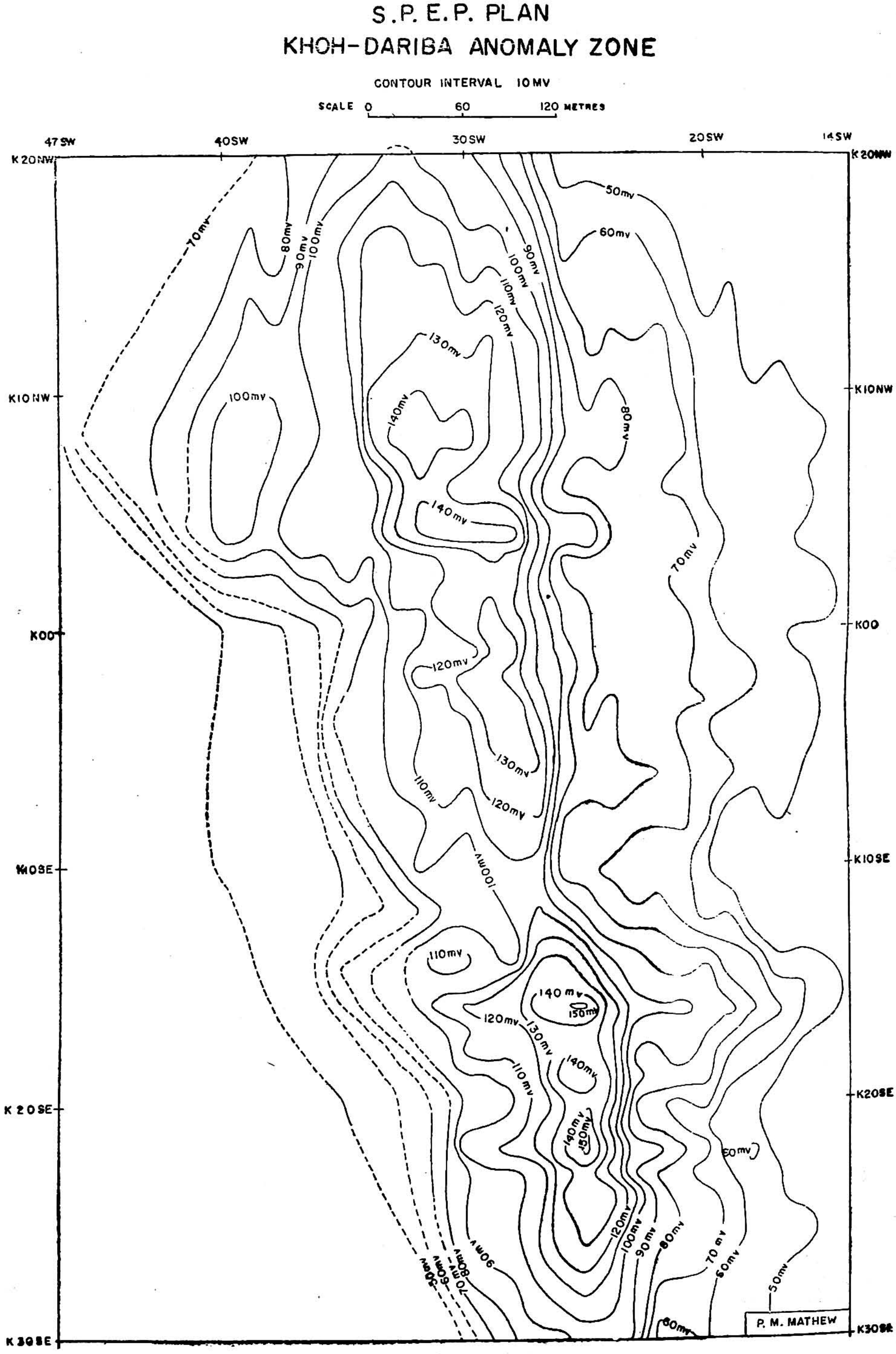


PLATE 61


S.P. E.P. PLAN
KHOH-DARIBA ANOMALY ZONE
CONTOUR INTERVAL 10 MV
SCALE 0 60 120 METRES
47 SW
40 SW
30 SW
20 SW
14 SW
K 20 NW
K 10 NW
K 00
K 10 SE
K 20 SE
K 30 SE
50mv
60mv
70mv
80mv
90mv
100mv
110mv
120mv
130mv
140mv
150mv
P. M. MATHEW

to minus 150 millivolts. A band of phyllites bounded on either side by faults runs through this anomaly zone located on the north-eastern flank of the Khoh-Dariba hill. Grits and quartzites occur in the upper part of the flank while in its lower part a band of ferruginous marble and gneiss is present.

The traverse lines BN 20 to BS 40 covered the area about 800 m. S.S.W. of △ 911 and adjoining areas. Self-potential measurements along these lines indicated a negative anomaly zone of comparatively smaller magnitude and extent, in the 'old pits area'. The maximum negative anomaly of minus 100 millivolts in this zone was observed at station 3W on B' S14 line.

The magnitude of the self-potential anomalies observed in the four anomaly zones described earlier is not very high and ranges from minus 100 to minus 150 millivolts. A study of the self-potential anomaly patterns in the four anomaly zones suggested that the causative bodies are not likely to be very massive and that they are fairly deep seated.

Magnetic Measurements : Magnetic measurements revealed large anomalies up to about 1,200 gammas only in the Dariba—Budhpura area. These anomalies, extending in a roughly north-south direction on the western flank of the Dariba hill were mostly over the rock formation of grits which contain a fair amount of magnetite. The high anomalies appear to be largely due to a magnetite band within the grits extending in a roughly north-south direction. There was little correspondence between the magnetic anomalies and the self-potential anomalies of the Dariba Mine and Dariba *nala* anomaly zones.

Magnetic anomalies of the order of 100 gammas were observed in the Khoh—Dariba area and in the area 2.8 km. N. N. W. of Baldeogarh.

Recommendations Made

On the basis of the results obtaind from the self-potential survey, exploratory drilling was recommended in the Dariba mine anomaly zone, the Dariba *nala* anomaly zone, the Khoh—Dariba anomaly zone

and in the small anomaly zone observed in the old pits area about 800 m. S. S. W. of △ 1911.

Subsequent Exploratory Drilling and Mining.

Subsequent to the geophysical surveys and geological and geochemical investigations of the area, exploratory drilling was carried out by the Department of Atomic Energy in the Dariba mine area. The Indian Bureau of Mines took over the exploration for copper in the Dariba mine and adjoining areas soon after and have carried out exploratory drilling in the Dariba mine, the Dariba *nala* Khoh—Dariba areas and in the 'old pits area' to the S. S. W. of △ 1911. Considerable amount of exploratory mining has also been carried out in the Dariba mine,

The results indicate that copper lodes of economic importance have been met with in the Dariba mine and the Dariba *nala* anomaly zones. Drilling carried out in the Khoh—Dariba anomaly zone met with only mineralised phyllites. No indication of any copper lodes of economic interest was obtained in this zone.

Acknowledgements

The author wishes to thank Shri B. Srikantan for valuable suggestions on the geological aspects of the survey and Shri A. K. Sen and Shri H. M. Shome for their cooperation and help in carrying out the geophysical investigations.

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GEOPHYSICAL SURVEYS IN THE KHETRI COPPER BELT WITH EMPHASIS ON ELECTRO-MAGNETIC STUDIES NEAR PAPRONA AND SINGHANA, JHUNJHUNU DISTRICT, RAJASTHAN

By

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Geological Survey of India.

(With Plates 62-67)

ABSTRACT

The paper presents the results of the geophysical investigations carried out by electric and magnetic methods for copper ore in the Khetri copper belt of Rajasthan.

Electro-magnetic data, around the prominent anomaly zones near Singhana and Paprona for different dispositions of the transmitter and receiver coils agree fairly well with those obtained by the self-potential, resistivity and magnetic surveys. A comparative study has been made regarding the electro-magnetic anomalies outlined near Singhana and Paprona.

In the Paprona-Babai section, the test boreholes drilled, struck graphitic scihists associated with traces of chalcopyrite in a fault zone. Two boreholes near Singhana revealed the occurrence of chalcopyrite at depth.

INTRODUCTION

An electro-magnetic inductive instrument, constructed in the Geophysical Laboratory of the Geological Survey of India, was used for some test observations in the Khetri copper belt of Rajasthan, where a number of prominent anomaly zones have already been outlined by systematic self-potential resistivity and magnetic surveys.

Previous Work

Systematic electrical and magnetic surveys in the Khetri copper belt, Rajasthan were taken up during the field seasons 1953-54 and 1956-57. A number of prominent electrical and magnetic anomalies

were obtained, and test drilling was recommended to verify some of the promising indications (S. N. Sen Gupta, 1955, M. N. S. Rao, 1956; H. V. N. Rao 1958).

Topography and Geology

In and around the areas, surveyed near Paprona and Singhana, the topography is practically even, the maximum topographical relief being of the order of 4.5 m. only. The major parts of these areas are under cultivation. The depth to water level, as observed in wells near Paprona, is about 18 m. from the general ground level, while that in Singhana is of the order of 21 m.

A detailed study of the geology of these parts of Rajasthan has been made by A. M. Heron (1917-23). In the area around Paprona, the rock formations met with are calc-gneisses, limestones, marbles, quartzites, and veins of pegmatites which are highly weathered at places. The general strike of the rock formations is more or less north-south and they dip steeply to the east at an angle of about 70°. The mineralisation in this area, where inductive electro-magnetic measurements were made, has occurred in the marble band. The major part of the area surveyed is under cultivation and the geology ts completely concealed under the alluvium. A number of old workings are seen in and around the area but primary minerals like chalcopyrite are not seen in any of these workings, although malachite stains in the dump material around the old workings are not infrequent. According to a local report, pyrite was struck at a depth of about 21 m. in a well close to the area surveyed

In the Singhana area, the actinolite-chlorite schist, which seems to have been a favourable host rock for copper ore, is garnetiferous in the Mandhan mine area (28°04′ : 75°49′) located on the crest of mineralised range comprising chlorite-schist and amphibolite, and flanked by felspathic quartzite on the east and mica-schist and phyllites on the west. Mineralisation is usually seen either in the contact zone between amphibolite and schist, or amphibolite and quartzite. Chalcopyrite is the predominating copper mineral and is associated with minor amounts of pyrite and pyrrhotite, while magnetite is seen at a few places. The secondary mineral malachite seems to have been mined by the ancients. Smell of sulphuretted hydrogen can be detected in some of the wells in the vicinity.

Method and Instrument used

The electromagnetic inductive method of prospecting consists essentially in studying the distortion of the alternating electromagnetic field established by an oscillating source, due to the presence of conductive bodies within the field. An alternating electromagnetic field is used to excite the conductor, and consequently, those minerals, which exhibit a high conductance when measured with alternating current, should be detectable fairly easily. The electro-magnetic radiation from the transmitting coil stimulates currents of the same frequency in the conductor. These secondary currents in the conductor will themselves cause a radiation of the same frequency, and therefore, at points on the surface above, there will be resultant electromagnetic field at any instant due to the superimposition of the field, and that due to the currents induced in the conductive body by the primary field. Owing to the presence of the direct radiation from the transmitter coil, the detection of the radiation from the conductive body presents some difficulty. The amount and nature of distortion of the primary field due to the interactions of the secondary field produced by a buried conductor depends on the various electrical constants of the surface and sub-surface materials, their spatial distribution in the field, the shape and disposition of the conductive body, the nature of electrical excitation of the body by the primary field, and the parameters of the field under examination. The parameters of the field at a point include its time or space phase relationship with the primary field, its total magnitude or any of the cardinal components. It is, therefore, evident that a large number of setups are involved as the conductive body may be stimulated in a large number of ways for determining one or more of the field parameters.

For an effective interpretation of the field data, a set of experiments would be helpful to study the natue of distortion of the primary field produced by idealised conductive bodies. Proper correlation of the field data with the data obtained from experiments will lead to important conclusions in respect of the location, disposition or conductivity of the body investigated.

The electro-magnetic methods of electrical prospecting for locating ore-bodies are being extensively employed for this purpose in Aus-

tralia, Sweden, Germany, U. S. A. and Canada. Such methods may broadly be classified into two categories namely, (1) electro-magnetic galvanic methods using grounded electrodes and (2) electro-magnetic inductive methods using currents imposed into the ground nonconductively. All these methods make use of an artificially created electromagnetic field produced either by (1) a horizontal loop or system of conductors, or (2) a vertical loop, the source of alternating current being a suitable generator in each case.

The inductive methods, in which current is applied to the ground by induction from insulated loops suitably disposed, are of particular advantage in rocky and arid districts where the passing of current conductively using grounded electrodes presents difficulties owing to high contact resistances. The other advantage of the inductive over the conductive methods is that the fields set up by the former can reach a body lying beneath a highly insulating layer, whereas the currents applied by the latter method may be unable to do this. A highly conductive surface layer, on the other hand, acts as a screen to the strata beneath it, and eventually gives rise to extremely unfavourable conditions for both the methods.

The electro-magnetic method is applicable for the detection of ore bodies fully above the water table, whereas the spontaneous polarisation method may fail under such conditions. While the S.P. method is restricted to such ore bodies and geological features which develop spontaneous polarisation, the electro-magnetic inductive method depends only on the conductivity contrast between the body to be located and its surrounding medium. The electro-magnetic instrument used for the investigations is designed for operation at frequencies of 1,200, 850 and 600 c.p.s.

Paprona area

Survey layout and field procedure

A reconnaissance survey was made around the anomaly zones near Paprona (27°56′ : 75°49′) and Singhana (28°06′ ; 75°50′) with a view to select a suitable area presenting a more or less flat terrain with promising S.P. and/or resistivity anomalies. The known important

copper workings in the Khetri copper belt, being situated on hill tops, were not amenable for test measurements by this electro-magnetic instrument. Detailed S.P. and resistivity measurements, carried out recently, revealed a pronounced conductive zone extending almost in a north-south direction about a mile east of Paprona. In view of the favourable terrain conditions, this area was taken up in the first instance for test electro-magnetic measurements.

A grid, 304 m. in length and 152 m. in width, was laid around the anomaly zone (Pl. 62.) The base line 0 was taken more or less along the axis of the S.P. anomaly and the traverses N 5, N 15 and N 25 were laid orthogonal to the base line at distances of 30, 92 and 152 m respectively to the north of station 0 on the base line. Similar traverses were also laid to the south and they are marked S5, S15 and S25. The stations on all these traverses were normally spaced at 6.6 m. intervals; the station to the east of the base line are designated as E1, E2, E3 etc. while those to the west are marked W1, W2, W3 etc. A number of traverses were also laid parallel to the base line at 30 m. intervals ; the traverse to the east is marked as E5, and the traverses to the west are designated as W5, W10, W15 and W20. On these travers esalso, the stations were spaced at 6.09 m. (20 ft.) intervals. Stations to the north of station 0 are designated as N1, N2, N3, etc. Similarly S1, S2, S3, etc. signify the stations to the south.

To facilitate S.P., resistivity and magnetic measurements, traverses N5, N15, S5 and S15 were extended to the east up to E25, keeping the station interval 6.6 m. as on normal traverses.

Three radial setups were taken with S20/W10, N5/W7½ and N15/W7½ as the centres for the different arcs having 30.5 m. (100 ft.), 45.7m. (150 ft.), 60.9 m. (200 ft.) and 76.2 m. (250 ft.) respectively as radius. All these arcs subtend an angle of 100° at their respective centres. The stations on these arcs were staked for angles of 10°, 5° or 2°30′, according to necessity. For 10° intervals along the arc, the stations were marked - 4, 0, 4, 8, 12 etc. Thus for 5° intervals along the same arc, the station numbers were - 4, - 2, 0, 2, 4, 6, 8, etc., while for 2°30′ intervals, the corresponding station numbers were - 4, - 3, - 2, - 1, 0, 1, 2, 3, 4, etc.

Various dispositions of the transmitter and the receiver coils can

be adopted for electro-magnetic measurements in the field with a view to study the response of conductive or resistive bodies within the field of measurement. In the area near Paprona, however, the following setups were used :—

(1) *End-on position :* Both the transmitter and the receiver coils were kept vertical and in the vertical plane joining the two coils.

(2) *Broadside-on position :* Both the transmitter and the receiver coils were kept vertical and perpendicular to the vertical plane passing through the transmitter and the receiver.

(3) *Horizontal :* Both the transmitter and the receiver coils were kept horizontal.

(4) *Zero direct coupling :* The transmitter coil was kept vertical, facing the receiver coil and the receiver coil was kept horizontal in the same horizontal plane as the centre of the transmitter coil.

For electro-magnetic measurements along traverses N5, N15, S5 S15, etc., as also along traverses E5, 0, W5, W10, etc., the first three arrangements mentioned above were adopted. Setup 4 could not be used as the sensitivity range of the receiving unit is limited to a distance of 76.2 m, (250 ft.) 91.4 m. (300 ft.) from the transmitter coil. For all these measurements, the transmitter coil was kept fixed and only the receiver coil was moved from one station to the other along a particular traverse.

For measurements with constant separation between the transmitter and the receiver coil, however, all the four setups were adopted as the distance between the transmitter and the receiver coil did not exceed 60 m. Such measurements were made on traverses N5, N15, S5, S15, etc. For these measurements, both the transmitter and the receiver coils had to be shifted in steps of 6.0 or 3.0 m. according to necessity.

In the case of radial type of arrangements of transmitter and receiver, only the setup 4 was used. The transmitter coil was kept in the centre of the arcs, namely A,R,C, marked in Pl. 62 and the receiver coil was moved along the arcs from one station to the other

zero direct coupling setup was achieved by rotating the transmitter coil in suitable setups of 10°, 5° or 2°30′ according to requirements.

The receiver coil was tuned only for the frequency of 1,200 c.p.s. as such, all electro-magnetic measurements were made for operation at that frequency.

In the Paprona area, an aggregate of 3,000 electro-magnetic measurements were made in addition to about 200 S. P., 100 magnetic and 100 resistivity observations.

Data obtained and discussion of results.

The S. P. measurements made on four traverses, N15, N5, S5 and S15 indicate a consistent negative anomaly around station O. The maximum S. P. value recorded was of the order of—210 millivolts. Two of the typical S. P. profiles for traverses S5 and N5 are depicted in Plate 62 for a comparative study with the correspoding electro-magnetic, resistivity and magnetic data. On the basis of S. P. readings obtained for the four traverses, S. P. equipotential contours were drawn and S. P. centre thus obtained was well defined (Pl. 64). It is interesting to note that the axis of S. P. anomaly trends more or less in north-south direction and is the same as the general strike direction of the rock formations. The depth to the causative body, as computed by the half-value method, is of the order of 15.0 m.

The resistivity data, obtained on traverses N5 and S5 for three different electrode separations (Wenner system), has brought out a resistivity 'low' west of station O (Pl. 62). It may also be seen that the conductive zone was slightly shifted to the west in relation to the S. P. anomaly zone. It is worth mentioning here that the transverse resistivity measurements taken in this area earlier indicated prominent conductive anomalies. The distortion observed in the resistivity profiles between stations O and E10 for both the traverses S5 and N5 is probably indicative of a fault zone in the vicinity.

The magnetic anomalies are probably due to the association of magnetite and pyrrhotite with the primary mineral chalcopyrite. Between stations E5 and E10 (Pl. 62), the rapid variation in the magnetic values is possibly indicative of a formal change or a fault zone.

Furthermore, it is interesting to note that the magnetic negative centre with slight lateral shift towards the north of the S. P. centre (Pl. 64) was located close to the axes of S. P. and electro-magnetic anomalies.

Electromagnetic observations were made with three different dispositions of the transmitting and the receiving coils, namely, end-on, broadside-on and horizontal, on six traverses, N25, N15, N5, S5, S15 and S25, keeping the transmitting coil fixed at W17½ on all these traverses and moving the receiving coil on all the stations for the different traverses. The magnitude of the transfer impedance (i. e. V/I, where V is the voltage induced in the receiving coil, and I is the transmitting coil current) between the transmitter and the receiver coil was plotted after taking out the inverse cube free space decay by multiplying the impedance by the cube of the distance 'd' between the transmitter and the receiver. Thus, $V/I.\ d^3$ in ohm-feet^3 was plotted for all the stations. In Plate 63, two typical electro-magnetic profiles are shown along with the S. P. resistivity and magnetic profiles for comparison. It may be observed that, for all the three electro-magnetic setups, a prominent 'high' was obtained over the conductive zone. The peaks were, however, slightly displaced in the different setups. The electromagnetic data fairly corroborated the data obtained by other methods.

A number of readings were taken on traverses parallel to the strike direction of the formations. Here also, the transmitting coil was kept fixed at station O on all the traverses and measurements were made for different stations lying on either side of the transmitting coil for three setups. From these readings, we can take a set of readings for a particular separation of the transmitting and the receiving coils. Thus, a set of readings for d=30.48 m. (100 ft.) will correspond to transverse electromagnetic measurements made on a traverse lying midway between the transmitting and the receiving coils, Similar values may be obtained for d=60.96 m. (200 ft.), 91.44 m. (300 ft.), 121.92 m. (400 ft.) and 152.39 m. (500 ft.) for traverses lying 30.48 m. (100 ft.), 45.72 m. (150 ft.), 60.96 m. (200 ft.) & 76.19 m. (250 ft.) from either the transmitting or the receiving coil. Such sets of values may be obtained for either side of the transmitting coil position, i. e. station O. Some of these profiles are shown in Plate 63 for three setups, end-on, broad-

side on and horizontal. It may be seen that stronger indications were obtained for end-on and horizontal configurations for larger values of separation between the transmitter and the receiver. On the other hand, for the broadside-on configuration, indications obtained for smaller separations fizzled with increasing separation between the transmitting and the receiving coils.

Electro-magnetic measurements were also made for constant separations of 30.48 m. (100 ft.) or 60.96 m. (200 ft.) between the transmitter and the receiver coils for four distinct configurations, end-on, broadside-on, horizontal and zero direct coupling, for all the six orthogonal traverses, N25, N15, N5, S5, S15 and S25. For all measurements, values of I/V were plotted for the mid-point of the transmitter and the receiver coil setup. Thus, when the two coils were at stations W10 and W5, I/V value was plotted on W7½ and so on for other setups. After each measurement, both the coils were shifted in steps of 3.04 m. (10 ft.) or 6.09 m. (20 ft.) in the same direction along the traverse for recording subsequent readings. As both the coils had to be shifted in the constant separation method, the progress was rather slow as compared to the type of measurements described earlier. In all these setups the coupling between the coils was maximum and, therefore, stronger indications were obtained for the primary field. The voltage induced in receiver coil due to the secondary current was rather feeble, so much so that, even after superimposition on the primary field, the overall variation of voltage was practically obscured. For zero direct coupling configuration, however, appreciable variations were obtained in the I/V values, although it is difficult to explain all the minor variations observed ; probably some of them are attributable to variable conductivities of the geological formations. From a critical study of the curves it may be seen that prominent 'lows' occurred near station W5 in the vicinity of the conductive zone delineated by S.P. and resistivity surveys. By the system of statistical moving average over a set of three readings, minor variations on these curves were smoothed out ; thus, average of 1, 2 and 3, was plotted on 2, average of 2, 3 and 4 was plotted on 3 and so on. The smoothed curves are shown in Plate 63 for comparison.

A series of observations were made with zero direct coupling configuration, the transmitter coil was kept vertical, facing the receiver coil, and the receiver coil was kept horizontal in the same horizontal

plane as the centre of the transmitter coil. The transmitter coil was kept at the centres of the different concentric arcs, A, R and C shown in Plate 64, while the receiver coil was moved in suitable steps along the different concentric arcs. The ratio of V/I (V being the voltage induced in the receiver coil, and I the transmitter coil current) was normalised by multiplying by a suitable constant ; the average value over the arc was obtained and the departure of each of the normalised V/I value from the average value was plotted in arbitrary units radially outwards with the average value over the arc as the zero level. This datum level was taken on the arc on which measurements were made. It is seen that the range of such values was within ±0.5. The shaded portions in Plate 64 are indicative of the regions where the vertical component of the field is above the average value for each of the individual arcs. It can be seen that, in the vicinity of the conductive body, the rise in the vertical component is well pronounced. Furthermore, the axes of the electromagnetic and S.P. anomalies are parallel to one another, although there is a relative lateral shift between the two' axes. Nevertheless, the axes follow the general strike direction of the geological formations. It is interesting to note that the magnetic (Vertical Force) negative centre lies very close to both the axes mentioned above.

Singhana Area

Survey layout and field procedure

As the electromagnetic data obtained in the Paprona area were found to be useful in corroborating the S.P., resistivity and magnetic data, it was thought worthwhile to try out some test electromagnetic measurements in the Singhana area where a number of pronounced S.P., magnetic and resistivity anomalies were outlined in earlier years (S. N. Sen Gupta, 1955, R. N. Chakravarty, 1960) the axes of S.P., magnetic and resistivity anomalies are shown in Plate 65. Two electromagnetic profiles were taken in the vicinity of the Geological Survey of India beacons 5, 6 and 7, in addition to radial setups shown in Plate 65. In the Singhana area, the electromagnetic measurements were made for constant separation and radial setups. In the constant separation setup, all the dispositions of the transmitting and the receiving coils, end-on, broadside-on, horizontal and zero direct coupling were

adopted. Such measurements were made on all the four traverses, where the pegs were spaced at 6.09 m. (20 ft.) intervals ; the nomenclature of the pegs was the same as adopted in the Paprona area. The stations to the north of the traverse were designated N, while those to the south were marked S. Thus, N1, N2, N3, etc. are the northern stations while S1, S2, S3, etc. signify the stations to the south.

The radials setup were taken with M and N as the centres for the different arcs having 30.48 m. (100 ft.), 45.72 m. (150 ft.) and 60.96 m. (200 ft.) respectively as radii. The stakes were fixed in the same way as at Paprona and the nomenclature was also the same. In the case of the radial setups, the transmitter and the receiver coils were kept in the zero direct coupling position.

In the Singhana area, about 1,000 electro-magnetic measurements were made The electro-magnetic data have corroborated the S.P., resistivity and magnetic data obtained during the previous season.

Data obtained and discussion of results

Four distinct configurations, end-on, broadside-on, horizontal and the zero direct coupling, were used for electro-magnetic measurements for constant separations of 30.48 m. (100 ft.) and 60.96 m. (200 ft.) between the transmitter and the receiver coils over all the four traverses. The values of I/V were plotted for the mid-point of the transmitter and the receiver coil setup. Both the transmitter and the receiver coils were moved in suitable setups for recording subsequent readings. In the first three setups, the coupling between the transmitter and the receiver coils was maximum and, therefore, stronger indications were obtained for the primary field, while the voltage induced in the receiver coil due to the secondary current was rather feeble. Thus, the overall variation of voltage was practically obscured, even after the superimposition of the primary field. For zero direct coupling configuration. appreciable variations were obtained in I/V values. Some of these variations are possibly attributable to variable conductivities of the geological formations, although some of the minor variations cannot be accounted for. The prominent 'lows' were obtained around station 0 in the vicinity of the conductive zone outlined by earlier S. P. and resisti-

vity surveys (Pl. 66). Minor variation on these curves were smoothed out by the system of statistical moving average and were subsequently plotted alongside the original curves for comparison (Pl. 66).

For the radial setup, the ratio of V/I was normalised by multiplying by a suitable constant ; after obtaining the average value over the arc, the departure of each of the normalised V/I value from the average value was plotted in arbitrary units radially outwards with the average value over the arc as the zero level. The shaded portions in Plate 67 are indicative of the regions where the vertical component is well pronounced. In the vicinity of the electromagnetic anomaly, as depicted by the radial setup plots in Plate 67 it is interesting to note that the axes of the S.P. and resistivity anomalies are parallel to the electromagnetic anomaly, although there is a slight shift between the different axes. Furthermore these axes follow the general strike direction of the geological formations in this area.

CONCLUSIONS

The new electromagnetic induction unit has given definite indications of the presence of conductive bodies near Paprona and Singhana of the Khetri copper belt in Rajasthan. The electromagnetic data collected agree fairly well with those obtained by S.P., resistivity and magnetic surveys.

Electromagnetic measurements over radial setups and along traverses laid orthogonal to the axis of the mineralised belt will be useful for reconnaissance as also for detailed surveys in the search of mineralised zones. Measurements with constant separation between the transmitter and the receiver coils are rather tedious and the progress of work is very slow ; as such, this system cannot be recommended for large scale investigations, although restricted measurements in selected areas will furnish useful data.

The data obtained with zero direct coupling configuration in conjunction with radial setups are promising. This can be used with advantage, by increasing the range of the instrument incorporating some mechanical device for adjusting the height of the receiver coil with respect to the centre of the transmitter coil, and also by increasing the transmitter power and receiver sensitivity appreciably.

From a comparative study of the radial setup plots for the

PLATE 62

ELECTROMAGNETIC SURVEY LAYOUT, PAPRONA AREA, RAJASTHAN.

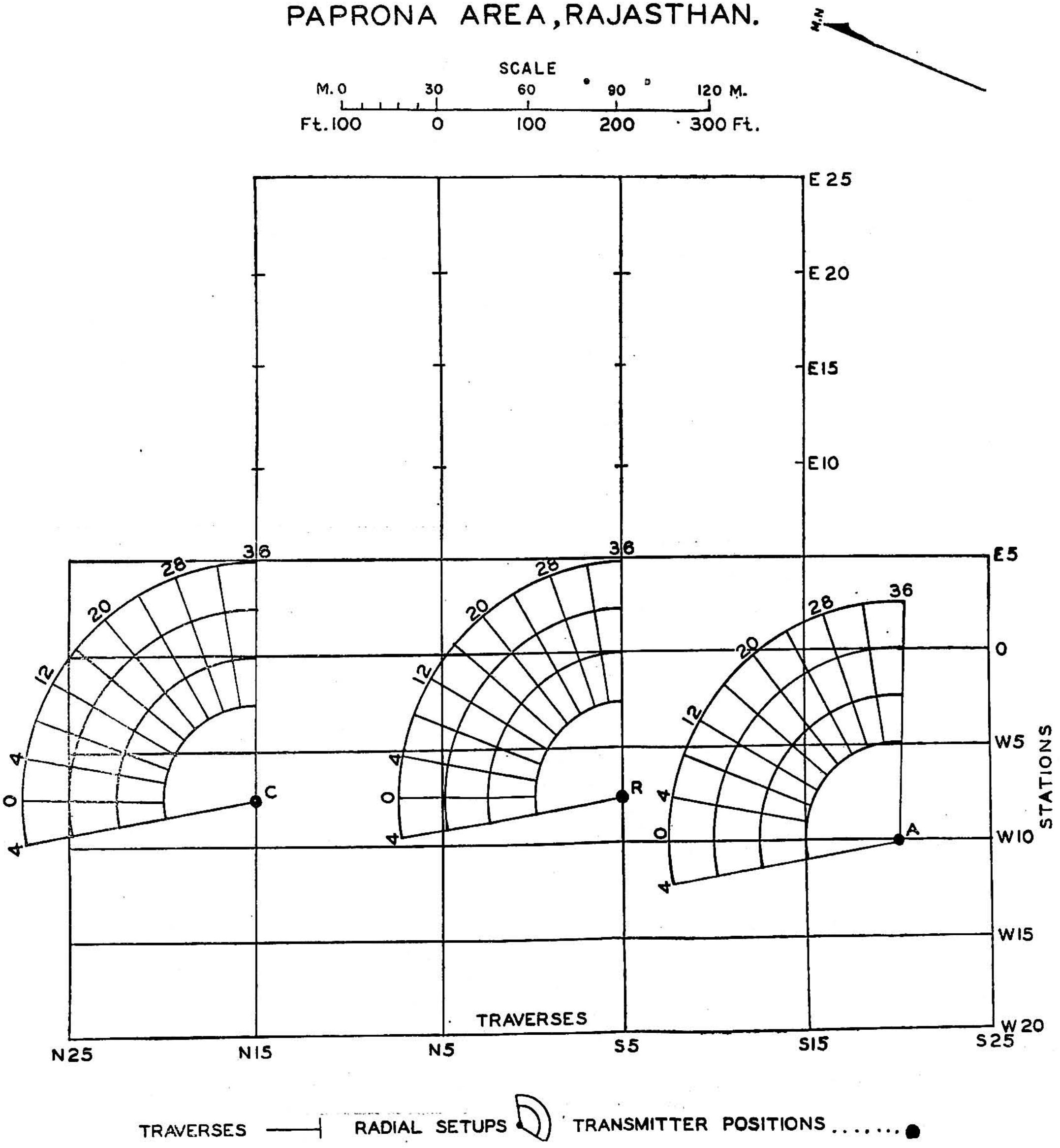
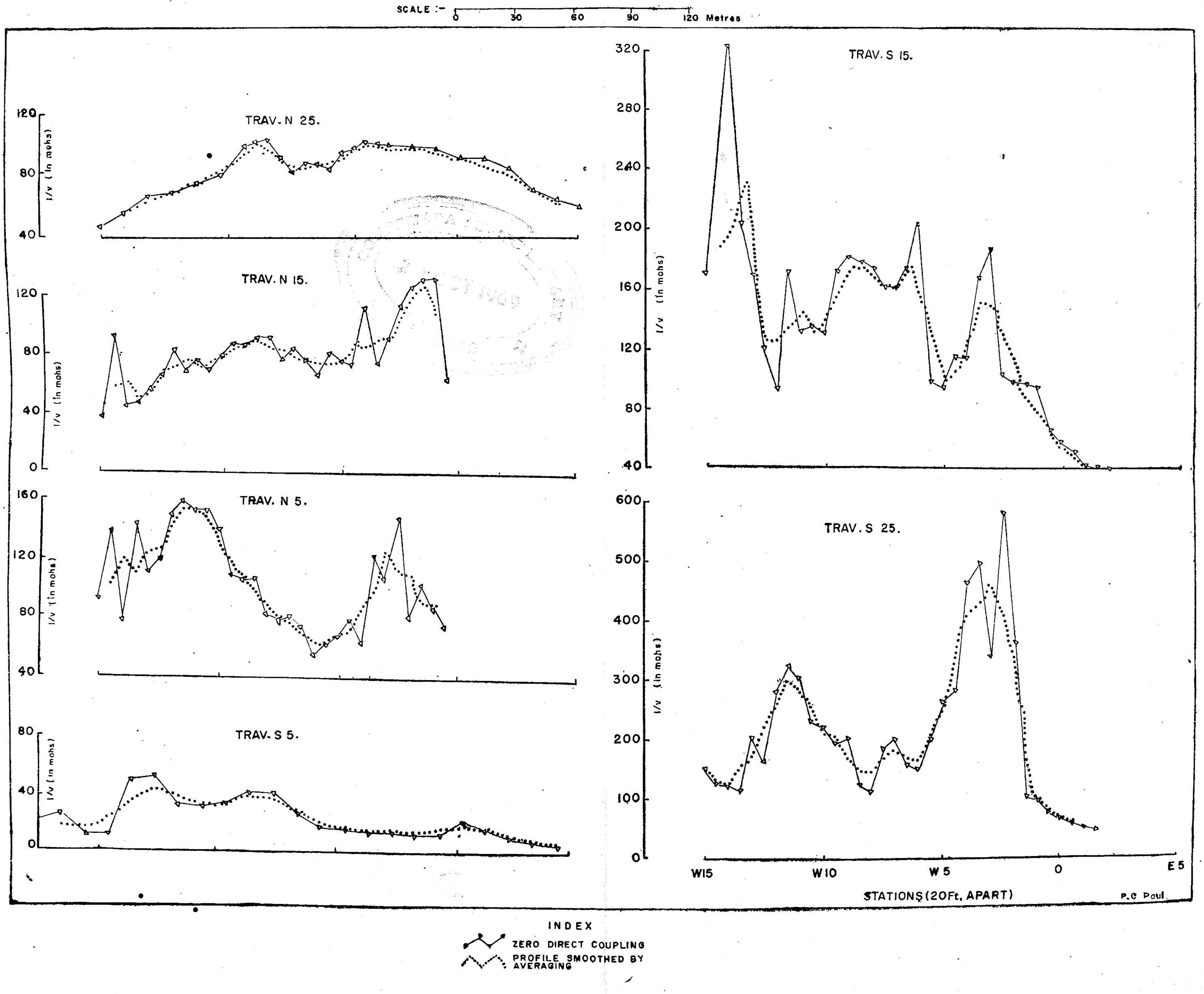
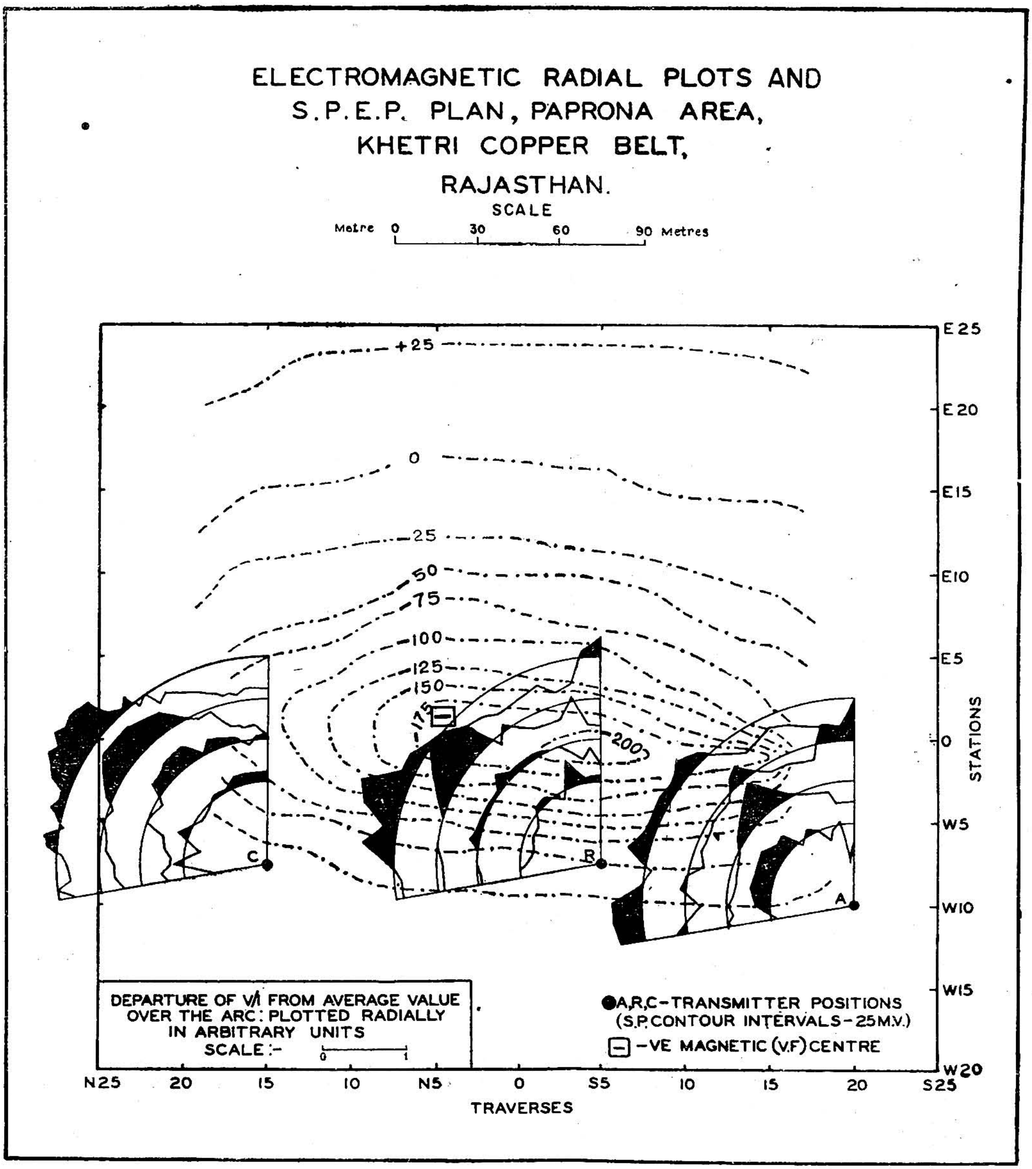
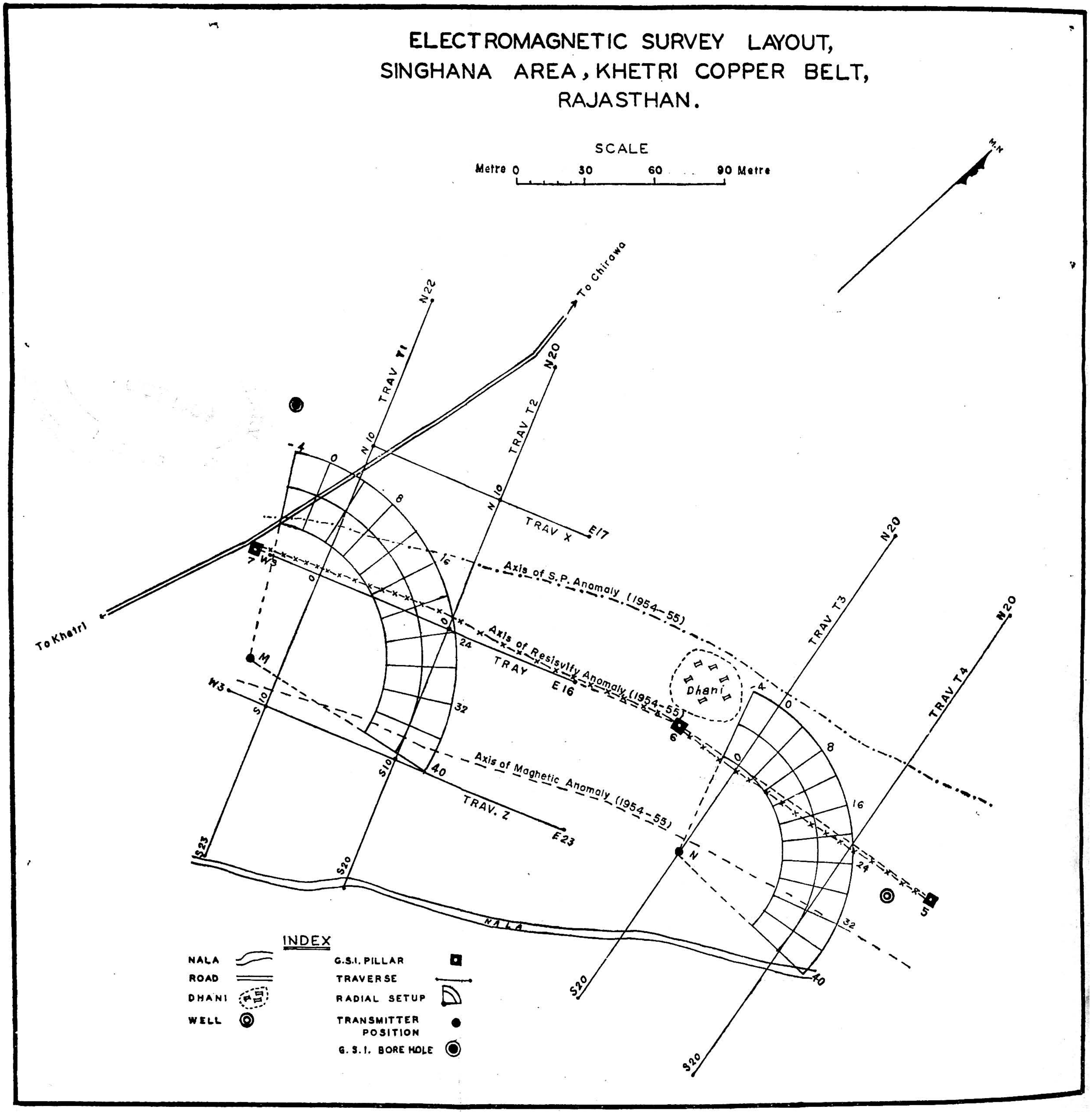


PLATE 63

ELECTROMAGNETIC PROFILES CONSTANT SEPARATION, PAPRONA AREA.
KHETRI COPPER BELT, RAJASTHAN




ELECTROMAGNETIC RADIAL PLOTS AND
S.P.E.P. PLAN, PAPRONA AREA,
KHETRI COPPER BELT,
RAJASTHAN.
SCALE
Metre 0 30 60 90 Metres
+25
0
-25
-50
-75
-100
-125
-150
-175
-200
E25
E20
E15
E10
E5
0
W5
W10
W15
W20
STATIONS
C
B
A
DEPARTURE OF V/I FROM AVERAGE VALUE OVER THE ARC: PLOTTED RADIALLY IN ARBITRARY UNITS
SCALE :- 0 1
A,B,C-TRANSMITTER POSITIONS
(S.P. CONTOUR INTERVALS-25M.V.)
-VE MAGNETIC (V.F) CENTRE
N25
20
15
10
N5
0
S5
10
15
20
S25
TRAVERSES


ELECTROMAGNETIC SURVEY LAYOUT,
SINGHANA AREA, KHETRI COPPER BELT,
RAJASTHAN.
SCALE
Metre 0 30 60 90 Metre
M.N
To Chirawa
To Khetri
TRAV T1
TRAV T2
TRAV T3
TRAV T4
TRAV X
TRAV. Z
TRAV
N22
N20
N10
E17
E16
E23
W3
S10
S20
S23
Axis of S.P. Anomaly (1954-55)
Axis of Resisvity Anomaly (1954-55)
Axis of Magnetic Anomaly (1954-55)
Dhani
NALA
INDEX
NALA
ROAD
DHANI
WELL
G.S.I. PILLAR
TRAVERSE
RADIAL SETUP
TRANSMITTER POSITION
G.S.I. BORE HOLE

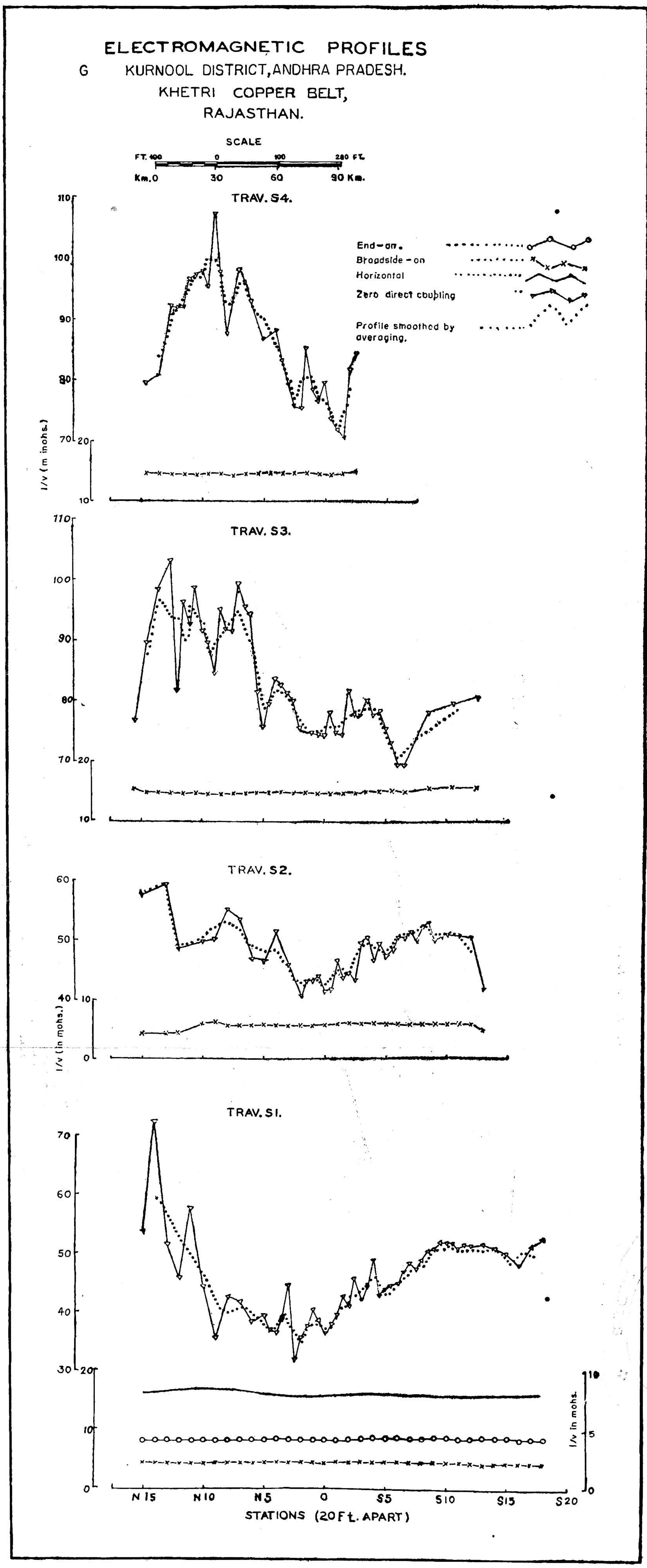


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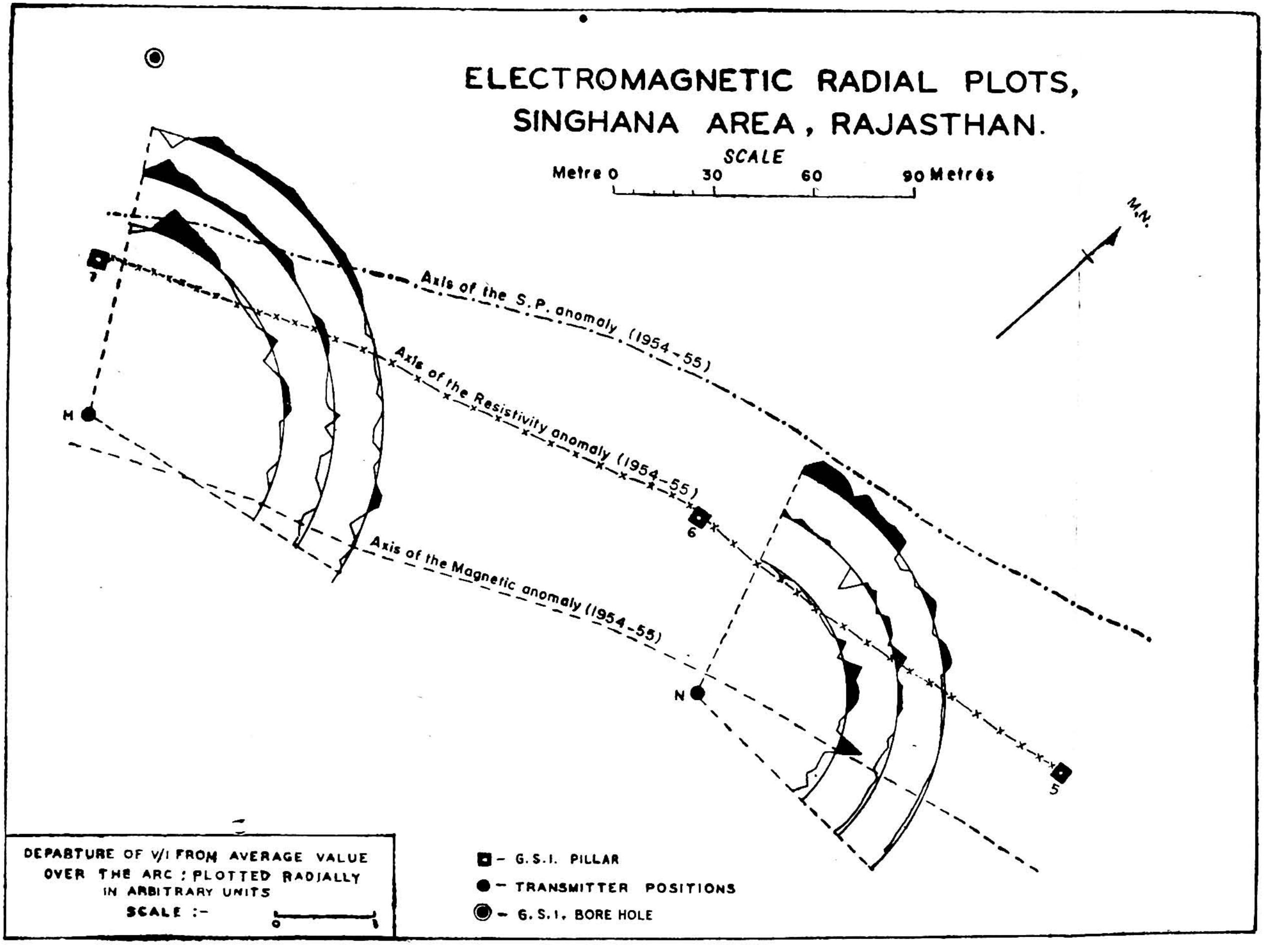
PLATE 67


ELECTROMAGNETIC RADIAL PLOTS,
SINGHANA AREA, RAJASTHAN.
SCALE
Metre 0
30
60
90 Metres
M.N.
Axis of the S.P. anomaly (1954-55)
Axis of the Resistivity anomaly (1954-55)
Axis of the Magnetic anomaly (1954-55)
7
6
5
M
N
DEPARTURE OF V/I FROM AVERAGE VALUE OVER THE ARC : PLOTTED RADIALLY IN ARBITRARY UNITS
SCALE :-
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- G.S.I. PILLAR
- TRANSMITTER POSITIONS
- G.S.I. BORE HOLE

Paprona and Singhana areas, it can be seen that the anomalies are stronger near Paprona when compared to those at Singhana. In view of this fact, it is reasonable to conclude that the conductor near Paprona possibly lies at a shallower depth in relation to that at Singhana.

Boreholes

The drill hole put down in the Paprona area revealed graphitic schist with minor dissemination of chalcopyrite in a fault zone. It is very likely that the electromagnetic anomalies are possibly associated with both graphitic schist and copper minerals, both of them being conductors.

In the Singhana area, the borehole struck copper at different depths and the percentage varied appreciably. The conductor was struck at greater depths when compared to the Paprona area. This fact, therefore, confirmed the view held from electromagnetic anomalies observed over the radial plots (Plates 65 and 67).

Acknowledgements

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ASSOCIATION OF URANIUM-BEARING MINERALS WITH COPPER-ORE IN INDIA

By

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ABSTRACT

A close association of uranium-bearing minerals with copper-ore has been observed in several parts of the world. The reported ocurrence of torbernite at one locality in the Singhbhum copper belt of Bihar led the Department of Atomic Energy to carry out detailed radiometric examination of all the major copper occurrences in India. It has been observed that uranium minerals are intimately associated with copper-ores in varying amounts throughout the Singhbhum Thrust Belt, in some of the copper-mine ares in Rajasthan and in some other parts of India. Quite a number of copper occurrences in Rajasthan are devoid of uranium mineralisation. In South India, except at Machnur in the Raichur district, Mysore State, the other copper-ores are free from uranium minerals.

The object of the paper is to draw attention to the possibility of winning uranium as a by-product of copper mining, and incidentally also augment supply of uranium from indigenous sources. Similarly any copper minerals associated with uranium-ores should be conserved.

INTRODUCTION

The closed association of uranium minerals with copper-ores has been reported from various parts of the world, *e. g.*, the rich Congo-Rhodesian copper belt including the well known copper and uranium deposits of Katanga; South Utah, North Arizona and South-West Colorado in U. S. A; Rum Jungle in Australia and Ferghana area in the U. S. S. R. In the initial stages of search for uranium ores in this country, the Atomic Minerals Division of the Department of Atomic Energy, devoted their attention to the Singhbhum copper belt and the copper deposits in Rajasthan and other areas, particularly because of the occurrence of torbernite (a hydrous phosphate of copper and uranium) at Sunargi (22°27′ : 86°33′) in Singhbhum.

SINGHBHUM COPPER BELT, BIHAR

Since 1950, the occurrence of uranium minerals was observed in a number of localities all along the Singhbum copper belt by a combined party of the Geological Survey of India, Indian Bureau of Mines, Department of Atomic Energy and the Damodar Valley Corporation. The entire 130 km. long Singhbhum Thrust Belt, extending from Duarpuram (22°46′ : 85°34′) in the west to Bahargora (22°16′ : 86°43′) in the South-East, has been investigated in detail by intensive drilling by the Department of Atomic Energy, aggregating to 49,682 m. and nearly 2,630 m. of underground development at Jaduguda (22°39′ : 86°26′) and Keruadungri (22°44′ : 86°11′).

Mosaboni and Badia Copper Mines:—Some officers of the Department of Atomic Energy, with the collaboration of the Indian Copper Corporation, examined the tailings of the copper-ore of the Mosaboni (22°31′ : 86°28′) and Badia mines (22°29′ : 86°28′) and found that they contain on an average 0.012 per cent eU_3O_8. After extensive experiments on beneficiation on a laboratory scale, a pilot plant was put up at Maubhandar (22°36′ : 86°27′) to up grade the copper tailings for extraction of uranium.

The extensive workings of the Mosaboni and Badia mines were radiometrically surveyed in detail. In the Badia mine, the uranium mineralisation appears more or less to coincide with the copper lodes, where as in the Mosaboni mines and in some zones containing very low copper values uranium content was found to be high ; the reverse was also the case in some places.

In such places of high activity, readings of the order of 15 B. G. were obtained with a Geiger-Muller counter and bulk blast samples gave average assay values of the order of 0.05 per cent eU_3O_8, though locally values as high as 0.09 per cent eU_3O_8 were obtained.

In the Mosaboni and Badia mines, the uranium is present almost entirely in the form of uraninite; hence the ore is easily amenable to concentration by physical methods and by leaching.

The possibility of carrying out selective mining of the uranium

rich zones in the Mosaboni and Badia mines through the agency of Indian Copper Corporation was explored, but this was not found to be economically feasible without interfering with their operations.

Area between Surda and Ramachandra Pahar : Although all a long the Singhbhum Thrust belt, copper mineralisation is closely associated with uranium mineralisation the areas which contain copper-ores in commercial quantities generally do not contain uranium minerals of economic grade, *e. g.* the Rakha Mines, Ramchandra Pahar, Surda mine, etc. Similarly, in the Jaduguda uranium mine chalcopyrite occurs only in small quantities. Appreciable sulphide mineralisation consisting mainly of pyrite and pyrrhotite with some chalcopyrite has, however, been observed on the footwall side of uranium lodes in some cross-cuts and boreholes.

Roam-Sidheshwar : In 1953-54, radioactivity was observed in an old adit driven for copper in the Roam area. A number of boreholes put down by the Department of Atomic Energy in that locality also gave fairly good values in uranium. More recently promising copper ores along with values in uranium-ores have been indicated in a number of boreholes put down by the Geological Survey of India, *e. g.* Nos. RMA—7, 8, 13, 15, 16, 19, 21 and RS—2 and 3. The more promising indications are as follows :—

RS—3	.071	per cent	eU_3O_8	75 cm.
RMA—8	.052	,,	,,	3.5 m.
	.045	,,	,,	2.5 m.
RMA—19	.087	,,	,,	5.5 m.
RMA—21	.053	,,	,,	30 cm.

In the underground workings of the Indian Bureau of Mines in the Roam-Sidheshwar block, promising indications of uranium have also been met with.

Keruadungri : At the Keruadungri, uranium prospects of the Department of Atomic Energy are situated about 4.8 km. south of Tatanagar R.S., chalcopyrite occurs only in minute quantities in the

uraniferous lodes, although comparatively richer lodes of pyrrhotite and pyrite have been observed on the footwall side in one or two boreholes which have been drilled well below the uraniferous horizon.

In the Singhbhum belt the mineralisation has followed planes of shearing associated with overthrusting from the north. Copper and uranium appear to be genetically related to the soda granite. From the field evidence and results of petrographic studies, it appears that uranium mineralisation is older than sulphide mineralisation, but is younger than the apatite-magnetite mineralisation.

RAJASTHAN

Khetri Copper Belt : In the Khetri copper belt, stretching for about 26.6 km. from beyond Singhana (28°06′ : 75°54′) in the north to Babai (27°53′ : 75°49′) in the south, indications of uranium mineralisation are observed at many localities in association with or close to copper lodes, but only in Kolihan area, west of Khetri town (28°00′ : 75°57′) aplite dykes and sills containing davidite (rare earth : iron-titanium oxide) with a maximum of 7-10 per cent U_3O_8 have been observed. The thickness of individual dykes ranges up to three metres and in some places two or three such dykes occur in close proximity.

The outcrops show gossan material in patches and occasional stains of autunite and torbernite. The radioactivity ranges from 2 to 15 time B. G., and locally picked material has given assay value as high as 0.2 per cent eU_3O_8.

In the northern portion of the area, secondary uranium minerals,—autunite and torbernite are observed along joints and cracks in epidiorite, intruded by veins of apatite.

Core drilling and underground development by Indian Bureau of Mines has shown that in Kolihan section a thick zone of copper mineralisation occurs on the footwall side of uranium bearing rocks. For example, gamma ray logging has indicated radioactivity in the following boreholes drilled by Indian Bureau of Mines.

Borehole	KKBH—2	...	0.1	per cent	eU_3O_8	over	30 cm.
			or 0.078	,,	,,	for	45 cm.

Borehole	KKBH—3	...	0.047	per cent	eU_3O_8	for	1.5 m.
„	KKBH—8	...	0.22	„	„	for	75 cm.
			0.092	„	„	for	0.75 cm.

Three successive boreholes drilled by the Department of Atomic Energy subsequently in the northerly continuation of the area have given the following results.

Borehole	DAE-KH—8	...	0.091	per cent	over	1.22 m.
			0.11	„	„	1.95 m.
„	DAE-KH—10	...	0.17	„	„	61 cm.
„	DAE-KH—11	...	0.087	„	„	91 cm.
		...	0.091	„	„	75 cm.
		...	0.21	„	„	61 cm.
		...	0.329	„	„	1.21 m.

Studies are now in progress to find out if it would be possible to economically recover uranium-ore from the mines develoded for copper in this section. The uranium and copper mineralisation are found to be parallel to each other, both having followed planes of foliation and shearing in phyllites of the Ajabgarh series of the Delhi system, but whether they are contemporaneous or not has yet to be established.

Dariba mine : In the lower of the two levels of the old workings of the Dariba mines, (27°10′ : 26°27′) which extend over a length of nearly 875 m. good indications of uranium ore were observed at two spots, which were explored by the Department of Atomic Energy by shallow cross-cuts and winzes and by drilling five boreholes. A close examination of the upper stopes showed promising indications and one small piece of hand picked mineral analysed as much as 54.78 per cent eU_3O_8. Since then the Indian Bureau of Mines have put down 22 surface and 11 underground boreholes and carried out about 2,743 m. of underground development in two levels in which locally promising indications of uranium mineralisation have been observed in the second level.

The uranium minerals occurs on the hanging-wall of the copper lodes in the form of discontinuous veinlets and streaks of uraninite following shear planes in slaty phyllites, and its mineralisation is probably controlled by the western shear fault. The old copper workings at Bhangarh (27°06′ : 76°21′) south-west of Dariba mine show radioactivity of five to six B.G. in the gossan zone.

Khandela : In the Khandela (27°36′ : 75°30′) and nearby Saladipura (27°38′ : 75°47′) areas in the Sikar district uranium minerals appear to be genetically related to the network of veins and lenses of kaolinised granite and pegmatitic material, probably of Erinpura age, which is injected into phyllites belonging to the Ajabgarh series of the Delhi system. It is associated with molybdenite, pyrrhotite and pyrite and sub-ordinate chalcopyrite.

Extensive pitting and trenching by the Department of Atomic Energy has shown that the uranium minerals occur as thin local stringers and as pockets of brannerite (oxide of uranium and titanium) ranging from less than two to twelve cm. in thickness. Picked specimens from these have analysed as mnch as 35 per cent. eU_3O_8. Drilling of 26 boreholes, aggregating 1,950 m. however, indicated that the total quantity of available uranium ore is very limited. The cores have been examined by the Indian Bureau of Mines with a view to exploring the possibility of working this deposit as a source for molybdenum, and if it materialises uranium and some copper can be obtained as a bye-product.

Umra : There are a few shallow old workings for copper in grids 1 and 2, stains of malachite and azurite are observed at the outcrop and in the recent underground workings for uranium in grids 1, 2 and 3, in the Umra mine area (24°30′ : 73°46′), which has been explored by the Department of Atomic Energy and also in other old workings 2.4 km. E.N.E. of the same. Small quantities of chalcopyrite are occasionally seen in the cores and underground workings and somewhat greater quantities of both chalcopyrite and bornite are observed in Adit No. 6 and in the underground borehole No. 37.

From the information available in ihe Geological Survey of India publications and from the results of field work, it appears that a zone

of copper mineralisation passing through Jagat (24°37′ : 73°52′), Tu (24°35′ : 73°52′), Tonk (24°30′ ; 74°32′), Sakroda (24°37′ : 73°56′), etc. runs more or less parallel to the radioactive belt extending from Kalamagra (Mera ka Gudha) (24°40′ : 73°45′) through Udaisagar (24°35′ : 74°50′) and Umra to Keora (24°22′ : 73°45′).

In the Umra area the uranium mineralisation follows shear planes and faults near the contact of carbon phyllites and calc-arenaceous rocks in tight, overturned folds, and appears to be genetically related to the Udaisagar granite which is exposed close by. Copper mineralisation occurs on the hanging wall side of the uraniferous lodes.

Bhinder : Some of the slags derived from the ancient smelting operations for copper carried out near Bhinder (24°30′ : 74°10′) contain U_3O_8 values ranging from 0.054 to 0.225 per cent the average being 0.113 per cent with practically no thorium, and about 50.80 tonnes of the same has been collected.

Chanpura : The extensive old copper workings in the hill on which the Kesarianath or Chuleswarji Jain temple is situated near Chanpura (26°35′ : 74°55′), east of Bhilwara (25°17′ : 74°38′) have given indications of radioactivity upto 4 B. G. but the uranium values are too low and erratic for this deposits to be worked economically for uranium alone. Detailed investigations by core drilling alone will show whether it can be taken up as a joint copper-uranium project.

PUNJUB

Kangara District : Minor quantities of chalcopyrite and pyrite have been observed under the microscope in sheared quartzite and chloritised phyllites near Chinjra (Kulu) in which radioactivity has been noted along joints and cracks.

UTTAR PRADESH

Garhwal (Pauri) District : Radioactivity of the order of 3-30 B. G. has been observed in carbonaceous and chloritic phyllites, chlorite-sericite schist and quartz-chlorite schist in and near the old copper workings near Pokhri village (30°21′ : 79°12′) and close to shop along Pokhri-Mohankhal bridle track.

Radioactivity has been recorded in the old copper workings in the Raja Khani mines at Chamethi (30°21′ : 79°11′) and old the waste dumps from the underground workings have shown activity of the order of 25 to over 30 B. G.

In the old copper workings south of Tonji (30°23′ : 79°12′) and in the *nala* between Tonji and Kimotha village, activity of 4-8 B. G. was recorded for 91 x 91 m. with higher readings of up to 25-30 B. G. at places. In a vertical exposure of 27.4 x 0.91 m. radioactivity of 3-18 B. G. has been recorded in which a 4.6 x 0.15 x 0.6 m. wide zone with thin veins and stringers of chalcopyrite is so active that the Geiger Muller counter needle swings off the scale.

Dhanpur Copper mine (79°06′ : 30°13′, 53/N/SW) : Old workings for copper situated 11.2 km. W.S.W. of Karnaprayag at an altitude of 836m. (2,743 ft.) and extending over a length of about 12.8 km. were examined in a preliminary manner and found to show low radioactivity of only two B. G.

Almora District : In the old copper workings at Gwaldum (30°00′ : 79°34′) where talc-chlorite schist alternates with granite gneiss bands and shows cupriferous stains and bornite, sporadic activity of 1.5 ta 3 B. G. has been recorded and samples radiometrically assayed 0.06 to 0.02 per cent eU_3O_8.

Old copper workings of Saunkoti (29°45′ : 79°38′) in gneisses, schists, and sandstones recorded activity of 2-5 B. G. with one patch showing 10-15 B. G. and samples from old workings have assayed 0.005 per cent and 0.082 per cent eU_3O_8.

Pithoragarh District: In the copper workings in mica-schist between Dewal Thal and Askot, activity of about two B. G. was recorded along the axis of a pitching anticline.

SOUTH INDIA

The only locality in South India, where minor radioactivity of the order of two to three B. G. was observed is in the old copper workings in epidiorite at Machnur (16°20′ : 76°45′) in the Raichur district, Mysore State.

OTHER OCCURRENCES

Quite a large number of ancient copper workings, examined in different parts of India including those in Madhya Pradesh, Bihar and Andhra Pradesh however, failed to give any indications of radioactivity. Some of those are :—

(1) Malpura near Salumbar (26°28′ : 74°38′) in Rajasthan, showing malachite.

(2) Copper workings near Delwara (26°07′ : 74°22′) investigated by the Department of Mines and Geology, Government of Rajasthan by core drilling.

(3) Lohakhan mine at the outskirts of Ajmer city (26°28′ : 74°38′) in Rajasthan; copious incrustrations of malachite and azurite on the walls of ancient workings and of chalcocite and bornite at the bottom of shallow winzes were observed.

(4) The copper occurrences at Mowsieki near Rani in Khasi and Jaintia Hills district, Assam.

(5) Daribo (27°49′ : 74°22′) in Bikaner district, Rajasthan 16 km. west of Talchappar R.S on the Degana-Ratangarh line.

(6) One mile east of Kishangarh R.S. (26°35′ : 74°54′), Rajasthan.

(7) Fairly extensive old copper workings at Salwari (27°39′ : 75°36′), Rajasthan.

(8) Old mine at Bairuki (24°35′ : 86°35′) in Monghyr district, Bihar.

(9) Old workings at Baragunda (24°08′ : 86°12′) in Hazaribagh district, Bihar.

(10) Copper mineralisation extending intermittantly over a length of about 128 km. through Sleemanabad (80°15′ : 23°35′) near Jabalpur, Madhya Pradesh.

(11) Copper mineralised zones of Agnigundala (15°45′ : 75°03′) and Gani (15°45′ : 76°03′) in the Cuddapahs, Andhra Pradesh.

(12) Garimanipenta area (15°59′ : 79°33′) in Dharwar schists, Nellore District, Andhra Pradesh.

(13) Ingaldhal (14°15′ : 76°28′) in cherty ferrugenous quartzite of Dharwar age, Chitaldrug District, Mysore State.

It may be mentioned that like copper-ores, uranium minerals are easily soluble in water and show high mobility, hence there is a possibility of striking higher uranium values in depth even where the surface indications may not be attractive. This can only be investigated by drilling or underground development.

From the above it would be observed that at least in the Singhbhum coper belt and in some areas in Rajasthan and possibly Garhwal Himalayas, some uranium can be obtained as a by-product of copper mining. In some localities where copper-ore is of marginal grade, the associated uranium ores may help to make the working economical.

SOME FUNDAMENTAL ASPECTS OF GEOCHEMICAL PROSPECTING FOR COPPER

BY

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ABSTRACT

Geochemical methods of prospecting has been widely accepted as the least expensive tool for rapid exploration of the hidden lodes. Geological Survey of India has been developing, modifying and applying these geochemical methods for exploration of metals.

Investigations on the nature of dispersion halos obtained by geochemical analyses for copper indicate that systematic controlled study of the top-soils over known lodes in varying climatic and geological areas should precede prospecting in the unknown areas. Geochemical anomalies are dependent on a number of diverse factors like (1) extent, nature and composition of the underground ore, bed rock and overburden blanket (2) age of the anomaly controlled by the climatic, hydro-geologic, topographic and geomorphic features of the district (3) supergene agencies affecting the ore and bed rock and (4) the pH, fineness and nature of clay minerals as well as organic matter of the top soil, on the migration and capacity of deposition for copper. The interpretation of soil samples is thus more or less specific for and restricted to particular districts of mineralisation. The data for successful geochemical investigations of one region cannot, therefore, satisfactorily be utilised in another.

It has been found that soil samples collected at a depth of 25—40 cm. from the surface are most representative for geochemical investigation. The halo system in the soil samples from Rajasthan, Almora and Singhbhum have been observe to follow distinct individual patterns.

INTRODUCTION

Defined in simple terms, geochemical anomaly implies a relatively high concentration of an element in a small area as compared to that in the background. It has been found on detailed study that the production of such anomalous concentrations, specially in materials

like soil, is quite a complex phenomenon and not at all, a case of statistical dispersion only.

There are various types of geochemical anomalies depending upon the material coming from a lode and the medium in which the anomaly is registered. It has been found that anomalies formed in soils of residual nature are the most useful for geochemical prospecting work. Considerable work has been done mainly in the U. S. S. R. and U. S. A. It is however, evident that much more work is required to put geochemical prospecting on a solid footing.

SOILS

It is essential to have an idea about the soil type on which an anomaly is to be interpreted. Not much is yet known about the soil types of Indian sub-continent that can be of direct help to geochemists. The Indian Agricultural Research Institute investigated 43 soil profiles all over India at a depth of about 30 cm. and classified the soil group on the basis of mechanical and chemical composition, base exchange, pH, salt content, etc. into the following types :-

(1) *Red soils covering a large part of peninsular India outside the area of the Deccan trap and of the narrow strip of coastal alluvium:* These have a light texture, porous and friable structure, with soluble salts less than 500 p. p. m. The clay fraction is rich in kaolinite. Not much is known about the yellow soils found side by side with the red soils.

(2) *Laterite and lateritic soils:* These are characteristic of tropical countries with intermittently moist climate and are well developed on the hills of Deccan, Mysore, Travancore, M. P., Rajmahal, the Eastern Ghat regions of Orissa, Bombay, Malabar and in parts of Assam. These are characterised by well drained, porous materials with varying amounts of humus.

(3) *Black soils of South India* : These are tropical black soils with loamy to clayey texture. Montmorillonite and beidellitic groups of minerals are present in these soils in large quantities.

(4) *Alluvial soils* : These are rather ill-defined and include many sub-groups like desert soils, saline and alkaline soils, meadow soils and forest soils.

It is evident that the investigations carried by the Indian Agricultural Research Institute, were conducted mainly from the agricultural point of view. It is necessary that soil samples from areas like Singhbhum, Khetri, Almora, Sikkim, Monipur, etc. are to be thoroughly examined for chemical, and mineral compositions in different mechanical fractions pH, copper exchange capacity (absorption, retention and formation of clay mineral complexes), humus and ratio of fixed to labile copper content.

Interpretation of Soil Anomaly

The interpretation of soil anomaly is more or less specific for and restricted to particular districts of mineralisation. Examples of successful geochemical investigations leading to virgin lodes are yet few in any country and those data cannot, unfortunately, be utilised in another region in the same or different country. Soil samples from Gohala, Machbhandar, etc. in the Singhbhum district were analysed geochemically at different depths. It has been found that soil samples at depths of 25-40 cm. are more representative for geochemical investigation. The halo systems in the soil samples from Rajasthan, Almora and Singhbhum, as expected, have often been observed to follow distinct patterns.

It may be noted that a minimum time interval is essential between the formation of the soil cover and the collection of geochemical samples, to allow for the attainment of equilibrium in the metal —solvent—soil system for any significant geochemical anomaly. A rough, yet effective measure of this time interval or age of the anomaly, is the thickness of the soil cover over the bed rock and is controlled among others by the climatic, hydrogeologic, topographic and geomorphic features of the district. A minimum of 40 to 65 cm. of soil cover is thus essential pre-requisite to geochemical sampling. Even under the above conditions seasonal variation must be taken into account. It is, therefore, suggested that as a pre-requisite to geochemical prospecting in all unknown and known areas laboratory control experiments should be carried out on the same components under varying conditions of temperature, pH and concentration. This is necessary to rule out ghost or spurious dispersion halos and peaks.

GEOCHEMICAL PROSPECTING

Copper is a metal for which geochemical prospecting is difficult. The diverse types of mineralisation, its complex geochemistry and its wide distribution in the earth's crust and presence of old workings in almost all copper districts of India, all contribute to the difficulty of successful geochemical prospecting for copper. The concentration of metal in soils is the outcome of the complex equillibria involving three major components, namely, the metal, the solvent carrying it, and the soil in which it is retained. The extent, nature and composition of the underground ore body determine the amount of copper that would be made available by the action of supergene agencies like air, carbon dioxide and groundwater. This is further controlled by the nature of the bedrock and the overlying sample of soil. Further, the dispersing and transporting potential of the solvent is extremely susceptible to changes in anionic species, pH and humus content, as far as solubility and migration of copper is concerned. It is a dynamic process somewhat akin to column chromatography, except that in this case the column is heterogenous and often changing due to vegetation; the time and temperature variables are also non-comparable to any known laboratory and industrial chromatographic process.

Geochemical prospecting is now a popular tool but caution must be excercised to convert it into an effective instrument and avoid unwise expenditure of time, money, men and materials as well as consequent disappointment.

Some of the above suggestions are being experimented upon in the Chemical Division of the Geological Survey of India. Soil samples from different areas where copper prospecting is in progress, are being investigated for the mechanism of retention of copper by bulk samples at different mesh size as well as on the different mechanical and mineralogical components.

GROUNDWATER SUPPLY FOR THE KHETRI COPPER MINE DEVELOPMENT, RAJASTHAN.

BY

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(With Plate 68)

ABSTRACT

Investigations were carried out in the Singhana and Jodhpura areas in connection with sources of groundwater supply to meet the annual demand of 8.5 million cu. m. (300 million c. ft.) water for the Khetri Copper Mine Development, Rajasthan. Geohydrological studies are in progress in the catchments of the Singhana river above Singhana and of the Kantli river above Jodhpura. The area is underlain by the consolidated rocks of the Delhi system, Post-Delhi epidorites, granites, pegmatites; and by the unconsolidated Recent Alluvium and blown sand. Groundwater occurs under water table conditions, the zone of saturation spreading through the consolidated and the unconsolidated rocks. The depth to the water table decreases towards the major river courses. The Recent Alluvium is saturated at several places, the most important ones being near Singhana and Jodhpura. Exploratory drilling in the Singhana area revealed the thickness of alluvium to be more than 30 m. Analysis of 127 water samples collected from the area shows that the chloride concentration ranges between 11 and 875 p. p. m., bicarbonate from 70 to 659 p. p. m., and pH value from 4.5 to 8.3. The quality of groundwater in the vicinity of the stream courses is generally superior to that in the adjacent areas. A study of the rainfall, extent of the catchments, recharge conditions etc. shows that there is scope for cautious optimism.

INTRODUTION

A Committee of Experts was appointed by the Government of India to examine a number of possible sources of water to meet the annual requirements of 8.5 million cu. m. (300 million c. ft.) for the Khetri Copper Mine Development, Rajasthan. It was of the opinion that, with respect to groundwater sources, the Singhana river basin above Singhna (28°06′ : 75°50′ ; 44 P) and the Kantli river basin above Jodhpura (27°48′ : 75°41′ ; 45 M) were worthy of further investigation which was actually taken up by the Geological Survey of India during 1960-62.

The catchment of the Singhana river above Singhana covers an area of 112.95 sq. km., and lies within Lat. 27°58′ to 28°06′ and Long. 75°42′ to 75°52′ (Sheet Nos. 44 P and 45 M). Northwards, the area investigated extends up to latitude 25°07′.

The catchment of the Kantli river above Jodhpura covers an area of 1014.37 sq. km. It lies within Lat. 27°30′ to 27°55′ and Long. 75°30′ to 75°55′ (Sheet No. 45 M).

The geohydrological studies include the measurements of water-levels, collection of water samples from wells for chemical analysis, lithological logging of exploratory boreholes, carrying out mechanical analysis of aquifer materials, collection of rainfall data etc. This work was carried out during 1960-61.

PHYSIOGRAPHICAL FEATURES

Topography : The area comprises broadly three hill ranges between (1) Singhana and Chinchroadli (27°50′ : 75°44′; 45 M) on the north, (2) Gurha (27°50′ : 75°38′ : 45 M) and Khandela (27°36′ : 75°33′ 45 M) on the west, and (3) Chiplata (27°34′ : 75°53′, 45 M) and beyond Gaonri (27°42′ : 75°50′, 45 M) on the east. The hill ranges rise at places to heights of more than 600 m. above m. s. l. The intervening plain country is scattered with isolated hummocks or sparsely connected ridges that are essentially erosional residuals or inselbergs, rising rarely to heights of more than 150 m. above m. s. l. Less important land forms comprise sand dunes, having heights generally ten metres above the valley floor.

Drainage : The drainage of the area is effected by the Singhana and Kantli rivers on the north and south, respectively. The Singhana river, originating near the hill-fort of Bhopalgarh (27°58′ : 75°47′, 45 M) flows northwards and is joined by several tributaries, the most important being the Kharkar nala. Both these rivers have a more or less linear course, confined to narrow valleys. The Kantli river has a reticulate pattern of drainage with numerous tributaries. The rivers are ephemeral and only in parts of their stretches they retain parennial pools of water derived from the effluent seepage of groundwater. Near

Jodhpura, the Kantli river flows through a gap in the hills which will be referred to here as the Jodhpura gap.

Rainfall

Most of the rainfall occurs during the south-west monsoon which lasts from June to September. The annual rainfall during the period 1885-1929 for two stations in the area, Khetri (28°00′ : 75°47′, 44 P and 45 M) and Nim-Ka-Thana (27°44′ : 75°47′, 45 M) is shown in Plate 68. The data are summarised in the Table 1 :—

Table 1

Summarised statement of Annual Rainfall in Khetri and Nim-Ka-Thana for the years 1886-1929.

Details	Khetri	Nim-Ka-Thana
Period of record	1886-1929 ; (44 Yrs.)	1890-1929 ; (40 Yrs.)
Maximum rainfall in cm. and year	114.0 ; 1908	123.90 ; 1917
Minimum rainfall in cm. and year	8.90 ; 1905	8.4 ; 1905
Mean annual rainfall in cm.	49.1	50.8
Number of years in which the rainfall was more than the mean	25	17
Frequency of years in which rainfall was more than the mean	1:1.76	1:2.35
Number of years in which rainfall was less than the mean	19	23
Frequency of years in which rainfall was less than the mean	1:2.32	1:1.74
Number of years in which rainfall was less than half the mean	3	2
Frequency of years in which the rainfall was less than half the mean	1:14.67	1:20

GEOLOGY AND WATER-BEARING PROPERTIES OF ROCK FORMATIONS.

The geological sequence of the formations met with in the area, is as follows :—

Recent and Sub-Recent : Alluvium, blown sand, etc.

Purana : Delhi system	Ajabgarh Series , Alwar Series	Intrusives	Pegmatites Granites Epidiorites

Delhi system : The rocks of the Delhi system as exposed in the area are mostly quartzites. The Alwars include limestones at places. The Ajabgarhs, in addition to quartzites and limestones, include slates (or phyllites) in the Kharkhar valley, micaceous schists near Khetri, calc-granulites near Nawabas (27°46′ : 75°44′, 45 M), Papra (27°45′ : 75°41′, 45 M), Chinchraoli (27°50′ ; 75°45′, 45M), Jodhpura, etc. The rocks are compressed into a series of folds and have a regional strike of N.E.-S.W. dipping N.W. or S.E. Near Khetri, Babai (27°53′ : 75°49′, 45 M) and several other places the phyllites carry significant amounts of copper-ores. The rocks of the Delhi system are generally well jointed at the surface, but few of the joints persist to great depths. In view of the greater surface slopes of these rocks, considerable part of the water received as precipitation is carried away as run-off.

Rocks intrusive into the Delhi system: The rocks of the Delhi system include, the epidiorites, granites and pegmatites. The epidiorites are seldom schistose while the granites are foliated at many places. These, by virtue of their lesser resistance to weathering, do not give rise to marked surface reliefs as do the quartzites of the Delhi system. The zone of weathering in the epidiorites extends downwards to more than about ten metres as seen in some of the wells near Gaonri and Kotera (27°47′ : 75°45′; 45 m).

Recent Alluvium : This comprises sand, gravel, pebbles and cobbles, mostly sub-rounded, in the Singhana area. In the Kantli river catchment, the alluvium is believed to be similar in nature. These are unconsolidated and do not have any cementing matrix, except within the capillary fringe, of calcium carbonate, above the water table. Mechanical analysis of 12 samples of drill-cuttings from

two exploratory boreholes in the Singhana area show that the effective size, screen size and uniformity co-efficients range between 0.203 and 0.787 mm., 0.356 and 1.956 mm., and 2.5 and 5.9 mm., respectively. In view of the coarseness of the materials, relatively small amounts of fines, sub-rounded nature, and the lack of cementing matrix, it is surmised that they are very porous, and when saturated, would yield water readily to wells tapping them.

Dune sands: The dune sand rests on the alluvium, or the older consolidated rocks. The sand is fine to medium grained, micaceous at places, and occurs extensively to the east of Shampura (28°01′ : 75°43′), Nawabas, Arjanpura (27°38′ : 75°44′), west of Khetri, and to a lesser extent, near Chirani (28°01′ : 75°50′), Ganesar (27°40′ : 75°49′), Singhana, etc. The fine blown sand readily absorbs rain water, and yields the absorbed water slowly down the slope.

Sub-Surface Geology

The basement on which the alluvium and the dune sand were deposited, comprise the rocks of the Delhi system, the intrusive epidiorites, the granites, etc. The thickness of the unconsolidated sediments is governed by the sub-surface topography of the older rocks as well as by the surface relief.

Sites for six boreholes in the Singhana area and for sixteen boreholes in the Jodhpura area were selected in order to determine the thickness and extent of the saturated alluvium. The available data indicated that the thickness of alluvium is, at places, of the order of 30 m. In the Kantli river catchment, the thickness of alluvium is more than 45 m. near the Jodhpura gap.

Groundwater Conditions

The main source of groundwater in the area is rain water part of which infiltrates into the soil and rocks till the zone of saturation is reached. Under the influence of gravity this water moves slowly towards areas of lower elevation.

In the area, groundwater occurs under water table conditions, the zone of saturation spreading through the rocks of the Delhi system, the Post-Delhi granites, epidiorites, the Recent Alluvium and also pro-

bably through the dune sand in some places. In the consolidated rocks the groundwater circulates mainly in the upper weathered mantle and the planes of structural weakness, such as joints, cleavages, faults, fissures, etc. In the unconsolidated rocks the movement of groundwater is through the pore-spaces between the grains.

In the Singhana area, between 21st February and 10th March 1961, in 152 wells, the depths-to-water were found to be within 42 m. Near Khetri, Chirani and Kharkhar and along the bed of the Singhana river upstream of Singhana, the water table was found to be within ten metres below land surface. In an elongated strip of area, about 800 m. in width and seven kilometres in length, parallel to the Singhana river, the water table lies in the gravel-bed of the alluvium at depths ranging between 5 and 16 m. This area commences about two kilometres south-west of Manuta (28°04′ : 75°50′, 44 P) and extends up to Singhana and probably further northwards. Alluvium is also saturated in the area south-west of Kharkhar, and in some parts along the course of the Kharkhar *nala*.

In the Kantli river catchment, between the 22nd March and 12th April, 1961, the depths-to-water were found to be within 37 m. below land surface. In most places along the Kantli river bed the water table lies within a depth of three metres, and at some places, *e. g.* near Kanwat (27°34′ : 75°42′) Kurbara (27°43′ : 75°46′), Budholi (27°42′ : 75°47′), etc. the water table rises very near to the land surface giving rise to saline efflorescence. From the river courses, the depths-to the water table gradually increase towards the drainage divides. The data collected so far indicate that the alluvium at several places is saturated. Large stretches of such alluvium occur along the course of the Kantli and its major tributaries. These stretches of alluvium are occasionally interrupted by buried ridges.

Quality of Groundwater

Singhana catchment : Samples of water from 74 wells were collected for partial chemical analysis. The water samples showed a range of 6.9 to 8.2 in pH values. A summarised statement of the results of chemical analysis of water samples from the Singhana area is given in Table 2.

Table 2.

Constituent	Number of water samples in range						
	0–50	50–100	100–250	250–500	500–1000	1000–2000	.2000–2008
Chloride p.p.m.	46	14	12	2	—	—	—
Bicarbonate, p.p.m.	—	1	8	59	5	—	—
Carbonate, p.p.m.	20	—	—	—	—	—	—
Total hardness as $CaCO_3$	—	—	31	38	4	—	—
Specific conductance in micromhos/cm. at 25°C	—	—	10	10	49	12	3

In general, the quality of water from wells in alluvium is superior to that from the adjacent consolidated rocks. Analysis of 18 water samples collected from wells in alluvium (above Singhana) showed the following range in quality.

Chlorides	...	11 to 76 p.p.m.
Bicarbonates	...	70 to 294 p.p.m.
Hardness as $CaCO_3$	...	148 to 279 p.p.m.
Specific conductance in micromhos/cm. at 25°C.	...	349 to 842.

In the consolidated rocks, the quality of water shows a wide variation, but a definite improvement is discernible towards the periphery of the hills.

Kantli catchment : Samples of water collected from 53 open wells in the Kantli catchment area were subjected to partial chemical analysis. The results are inadequate to critically discuss the variation in the quality of water in relation to the local geology. This aspect of the

investigation was interrupted due to the onset of the monsoon. A summarised statement of the results of chemical analysis of water samples from the Jodhpura area is given in the Table 3.

Table 3

Constituent	Number of water samples in range						
	0–50	50–100	100–250	250–500	500-1000	1000–2000	2000–3642
Chloride, p.p.m.	19	10	13	5	7	—	—
Bicarbonate, p.p.m.	—	—	11	38	5	—	—
Carbonate, p.p.m.	40	7	3	—	—	—	—
Total hardness as $CaCO_3$	—	2	25	24	3	—	—
Specific conductance in micromhos/cm. 25°C	—	—	—	4	23	18	9

The water samples are found to be mildly alkaline in reaction, with pH values ranging between 7.1 and 8.3. Broadly considering, the variation in the quality of groundwater is more pronounced across the regional strike of the rocks than along it.

Water Requirements and Water Resources

The annual water requirements for the mine development are about 8.5 million cu. m. (*i. e.* 23,360 cu. m. ad ay).

Catchment of the Singhana river above Singhana : The catchment area of the Singhana river above Singhana is about 113 sq. km. Assuming the rainfall figures for Khetri as representative of the catchment, in the year of minimum rainfall (8.9 cm. in 1905) the catchment, received roughly 10 million cu. m. of water as precepitation and in the year of maximum rainfall (114 cm. in 1908), about 128 million cu. m. of

water. If it is assumed that the rainfall variation in the future also will be of this order, then the annual requirements of water for the mine development represent 85 per cent of the rainfall in the catchment in the year of minimum rainfall and 6.6 per cent of that in the year of maximum rainfall.

Considering the groundwater resources, the strip of alluvium along the Singhana river holds promise for withdrawal of moderate amounts of groundwater by means of tubewells. The extent of the area where alluvium is saturated is about 5.7 million sq. m. If a conservative figure of 20 per cent as the specific yield of the saturated materials is assumed, complete dewatering of the upper 1.5 m. of the zone of saturation by pumping will yield approximately 1.7 million cu. m. of water. If this draft is spread through the year, a daily draft of 4,700 cu. m. is likely to be sustainable: The ultimate economic yield depends also on the amount of water that is replenished to the groundwater reservoir annually. This can be estimated more accuratley when the required exploratory wells are constructed, and aquifer performance tests conducted.

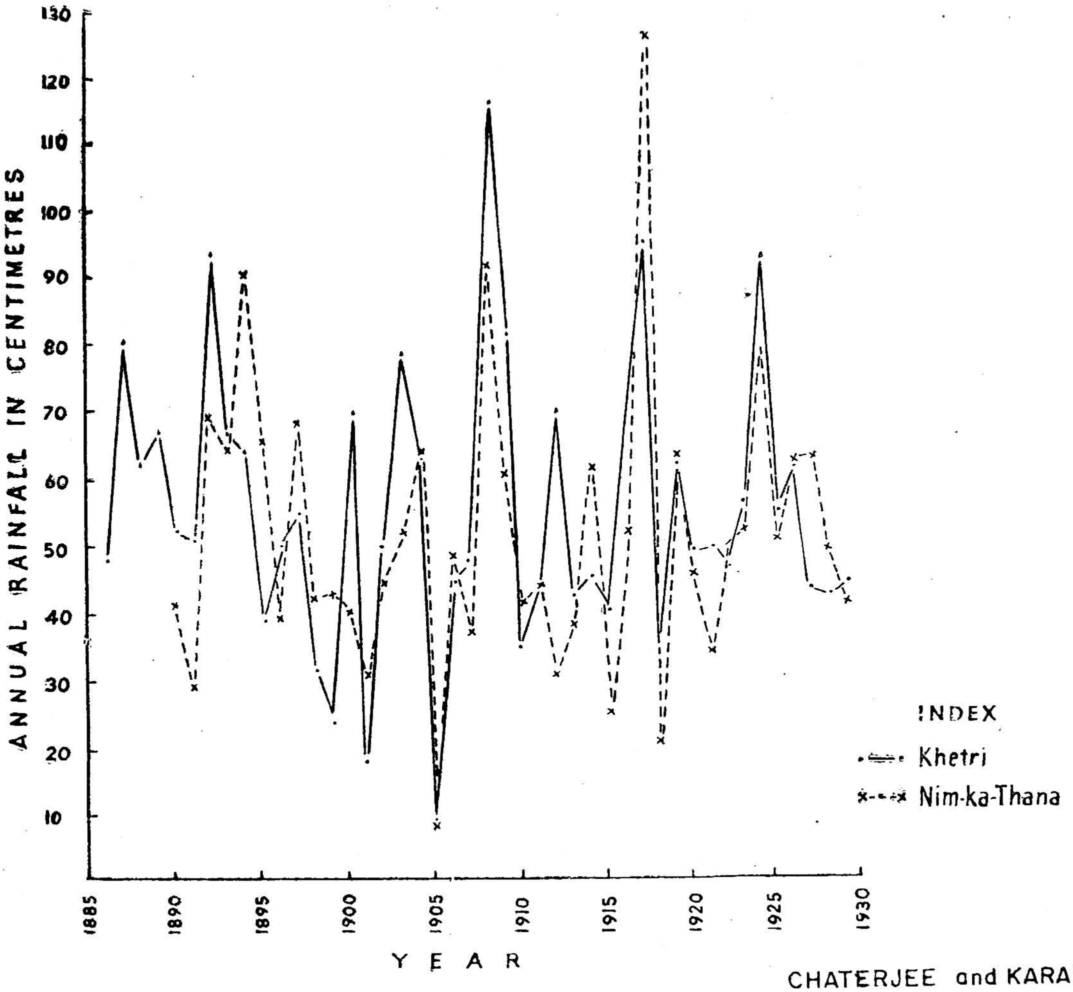
Kantli river catchment above Jodhpura : The extent of the catchment of the Kantli river above Jodhpura is roughly 1012 million square metres. Assuming that the rainfall figure for Nim-Ka-Thana is representative of the catchment, in the year of minimum rainfall (8.4 cm. in 1905) the catchment received about 85 million cu. m. of water as precipitation; and in the year of maximum rainfall (123.9 cm. in 1908), 941 million cu. m. of water. Assuming that the future variation in rainfall will also be of this order, the annual water requirements for the mine development represent apporiximately 9.9 per cent. of the rainfall in the catchment in the year of minimum rainfall and 0.9 per cent of that in the year of maximum rainfall.

As the demarcation of the extent of the alluvial reservoir in this area is still in progress (1962) this aspect of the problem cannot be discussed further at this stage.

CONCLUSIONS

The precipitatton in the Singhana area is evidently inadequate to recharge the aquifers to the extent of meeting the total demands

ANNUAL RAINFALL AT KHETRI AND NIM-KA-THANA



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for the mine development. However, it may be possible that moder ate quantities of groundwater may be withdrawn from the Singhana area to supply domestic requirement of the Copper Mine Colony, provided waste water from the mills is not discharged into the Kharkhar *nala* or any other part of the catchment.

The Kantli basin holds better promise to sustain groundwater drafts of the order of about 8 million cu. m. which observation, however, needs to be examined in the light of exploratory drilling and testing in the area. The results of the investigation so far indicate that there is scope for cautious optimism.

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